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## FORWARD

From November 1981 and concluding with this symposium, a committee with representation from Regional Research, Protection, and Silviculture sections has been meeting to examine the use of prescribed fire in the Prince Rupert Forest Region. Two of the objectives of this Prescribed Fire - Forest Soils Committee are:

1. to define and identify research priorities for this Region in the field of prescribed fire - forest soils, and
2. to promote better understanding of fire - soil relationships among forest managers.

In aid of achieving these objectives, the committee sponsored a symposium on the impacts of prescribed fire on forest soils, held at the Hudson Bay Lodge in Smithers on March 2 and 3, 1982.

The day and a half long session included presentations by experts and group discussions involving district, regional, and industry personnel. The intention of the symposium was to provide information to participants, and equally important, to serve as a forum for the exchange of views and concerns pertaining to the use of prescribed fire.

Rick Trowbridge (Regional Pedologist, Research) chaired the committee and edited the papers, and Anne Macadam (Assistant Pedologist, Research) chaired the symposium. Larry Hall (Planning Officer, Protection), Vern Hopkins (Fire Prevention Coordinator, Protection), Mike Geisler (Interpretations Forester, Research), and Jane Lloyd-Smith (Site Preparation and Reforestation Assistant Coordinator, Silviculture) were members of the committee and helped to organize the symposium.

The papers have not undergone technical review. Their content remains the responsibility of the author.

# FIRE HISTORY AND FIRE ECOLOGY IN THE PRINCE RUPERT FOREST REGION

John Parminter[1]

Abstract

Fire ecology knowledge is required for fire management operations as well as for other aspects of natural resource management. Natural fire has influenced ecosystem processes at various scales and has been a major factor in determining the composition and distribution of vegetation types. Different fire types and frequencies can be classed into fire regimes and these regimes related to the role of fire in different ecoystems.

Forest tree species and other vegetation possess varying degrees of fire tolerance and fire adaptations, or indeed may be totally dependent on fire for their continued existence. On the other hand certain vegetation species are fire sensitive and may be removed altogether or lessened in numbers by fire. It appears that fire has played a diverse role in the biogeoclimatic zones of the Prince Rupert Forest Region - from very rare in the Coastal - Cedars - Pine - Hemlock to very common in the Boreal White and Black Spruce. Post-fire vegetation development can follow one of several directions, the direction taken is determined by site characteristics, the nature of the fire, and subsequent environmental conditions.

Significant differences may exist between the natural fire regime and historical fire effects and the fire regime and fire effects imposed by man and his various land management activities. Guidance in the artificial application of fire can be obtained from a knowledge of the natural place of fire in the ecosystem in question.

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# FIRE HISTORY AND FIRE ECOLOGY IN THE PRINCE RUPERT FOREST REGION

## Introduction

Fire ecology was defined by Komarek (1979) as being "...the study of fire as it affects and relates to the natural environment and the interrelationships of the plants and animals therein." The study of fire as a force which influences ecosystem properties is therefore centred on fire's effects upon live vegetation and non-living fuels; soil and hydrologic processes; and all types of fauna.

Fire management was defined by Barney (1975) as being "...the integrating of fire-related biological, ecological, physical, and technological information into land management to meet desired objectives." The total fire management framework involves the "...concept that fire and the complex, interrelated factors influencing fire phenomena can and should be managed" (Barrows 1974). The scope of fire management necessarily involves the traditional activities of fire prevention, fuels management, fire suppression, fire site rehabilitation, and the use of prescribed fire but also includes consideration of the beneficial and/or harmful effects of fire as a natural process (Mutch 1975).

Natural resource management has historically been based upon maintenance of the status quo by minimizing negative interferences such as fire. However, as demands for production of a variety of goods from a finite land base increase, active management to maximize the output of nature becomes necessary (Kessell 1979). Such active management is predicated upon a knowledge of the environmental implications of artificial practices such as forest harvesting and natural ones such as fire.

## The Role of Fire as an Ecosystem Process

Wright and Heinselman (1973) summarized the basic roles of fire as follows:

- fire releases mineral elements from living and dead organic substances, with some elements being volatilized
- fire reduces plant cover shading and therefore increases the input of solar insolation which affects soil temperature and local microclimate
- fire regulates the accumulation of above ground dry biomass and can be a major determinant of nutrient cycling and energy flow
- fire may stimulate sprouting, flowering, and fruiting of shrubs and herbs and can trigger the release of seeds of serotinous tree species
- fire alters the seedbed and may create large areas of thin ash or humus, or bare soil
- fire may selectively eliminate part of a plant community and eliminate or temporarily reduce competition for moisture, nutrients, heat, and light
- post-fire levels of forage and browse plants may be higher than pre-fire levels and represent an important food source for certain wildlife species but forage in old growth forests such as tree and ground lichens will be reduced
- fire is an important regulator of insect populations and can terminate large outbreaks through the destruction of the host trees
- fire temporarily eliminates some plant parasites and may prevent the germination of some fungi
- fire can control the location of forest/non-forest ecotones as well as the local occurrence of plants
- fire (or the lack of it) regulates the total vegetation mosaic through fire size, intensity, and frequency; determining the relative abundance of plant communities and successional stages
- fire prevents a system-wide succession to climax forest stands by maintaining a mix of successional stages. This mix, coupled with fire's influence on setting or maintaining ecotone boundaries and controlling the local occurrence of plants influences the diversity of the entire ecosystem. The diverse mixture of fire-maintained successional stages may produce a more stable ecosystem.

Fire has become recognized as a major disturbance factor in many forest and non-forest ecosystems. Indeed, some ecosystems which require fire treatment to ensure their continued existence have been termed fire dependent by Habeck and Mutch (1973). The natural role of fire in the forest environment can be evaluated and understood more fully with a knowledge of the average, minimum, and maximum intervals between fires in various ecosystems; the intensities and sizes of these fires as well as their effects on stand composition and age-class structure (Arno and Sneck 1977).

## Fire Types, Fire Regimes, and Fire History

Fire types in forests can be divided into three categories (Brown and Davis 1973):

ground fire: fires which consume the organic matter beneath the surface litter of the forest floor, spreading within rather than on top of the organic mantle

surface fire: fires which burn the surficial litter and debris of the forest floor as well as low vegetation; fire behaviour is variable depending on conditions, may sometimes reach into the tree crowns

crown fire: fires which travel through the top layers of trees or shrubs, more or less independent of surface fires.

These three basic types of fire can occur singly or in combination, both in space and time. Consideration of the type and intensity of fire, fire size, and the fire frequency or return interval typically encountered for specific land units has lead to the definition of seven distinct fire regimes (Heinselman 1981):

0 No natural fire (or very little)

1 Infrequent light surface fires (more than 25 year return intervals)

2 Frequent light surface fires (1 to 25 year return intervals)

3 Infrequent, severe surface fires (more than 25 year return intervals)

4 Short return interval crown fires and severe surface fires in combination (25 to 100 year return intervals)

5 Long return interval crown fires and surface fires in combination (100 to 300 year return intervals)

6 Very long return interval crown fires and severe surface fires in combination (over 300 year return intervals)

Evidence of historic forest fires may be obtained by examination of fossil charcoal, charcoal in aquatic sediments, charcoal layers in soil horizons, burned stumps and snags, forest stand structure, historical records, and photographs. Definitive historical fire frequencies can be determined by analyzing annually laminated lake and bog sediments, historical records, the age structure of fire-initiated forests, and through dendrochronological analysis of fire-scarred living trees or dead snags.

Fire History and Fire Ecology of the Coastal, Interior, and Northern Portions of the Prince Rupert Forest Region.

The effects of fire can be examined at many scales, from micro to macro. From a perspective of vegetation, and forest trees in particular, we can consider the influence of fire on tree species, forest stands, and the forested landscape. Tree species vary in their adaptations to fire with respect to their ability to survive a fire, to seed into burned areas, or to vegetatively reproduce following fire. Table 1 shows the relative fire resistance of selected conifer species.

Table 1. Relative fire resistance for some conifer species (from Lotan et al. 1981 and Spalt and Reifsnyder 1962).

| Species | Thickness of bark of old trees | Root habit | Branch habit | Stand habit | Foliage flammability | Degree of fire resistance |
|---|---|---|---|---|---|---|
| Douglas-fir | Very thick | Deep | Moderately low and dense | Moderate to dense | High | High |
| Western redcedar | Thin | Shallow | Moderately low and dense | Dense | High | Moderate |
| Lodgepole pine | Thin | Variable | Moderately high and open | Moderately open | Medium | Moderate |
| Mountain hemlock | Medium | Medium | Low and dense | Dense | High | Low |
| Western hemlock | Medium | Shallow | Low and dense | Dense | High | Low |
| Engelmann spruce | Very thin | Shallow | Low and dense | Dense | Very high | Low |
| Sitka spruce | Very thin | Very Shallow | Moderately high and dense | Moderate to dense | Medium | Low |
| Pacific silver fir | Thin | n/a* | Moderately high and dense | Dense | High | Low |
| Subalpine fir | Very thin | Shallow | Very low and dense | Moderate to dense | High | Very low |

*no data available

Other adaptations to fire include cone serotiny (lodgepole pine) and semi-serotiny (black spruce) which allow the release of seed from fire-killed trees to the post-fire site. In contrast, species such as white spruce, Douglas-fir, western hemlock, western redcedar, and subalpine fir require live survivors on or near the fire site to provide wind disseminated seed. Certain hardwoods such as trembling aspen, paper birch, and alder are capable of prolific production of light seed which can travel considerable distances.

Vegetative reproduction by root suckering (trembling aspen), sprouting at the root collar (paper birch), or these two mechanisms plus the development of buried branches (balsam poplar) (Lutz 1955, Zasada et al. 1977) are also adaptations to fire. Lesser vegetation also possesses post-fire reproductive strategies such as sprouting from roots, rhizomes, and stems (willows, bog birch, Labrador tea, huckleberries, some herbaceous species) or production of many light wind disseminated seeds (willows, fireweed). Some species possess seeds which germinate following stimulation by fire (high bush cranberry, wild rose, red raspberry, pink corydalis) (Viereck and Schandelmeier 1980).

The absence or rarity of fire-adapted plant species on a particular site may be an indicator of a total or prolonged lack of fire, although over an extended time period fire has probably influenced most such sites:

> "The only environments not experiencing fire as a significant ecological factor were those that remained very cold, very wet, or very dry, and even in these regions, extreme variation in weather infrequently produced conditions for the spread of fire" (Agee 1974).

Thus, a broad range of fire influence exists and runs from environments which are rarely if ever visited by fire (regime 0) to those which burn relatively frequently (regimes 1,2,3, and 4). In the middle of this spectrum are sites which do burn, but do so rather infrequently (regimes 5 and 6). The frequency of fire influences the rate of accumulation of organic matter such that where fires are frequent they are also less intense. Where fires are infrequent they have a larger accumulation of organic matter (and hence available fuel) and tend to be more intense. In addition, in the cooler and moister areas of

North America the accumulation of organic matter exceeds the rate of decomposition, adding to the fuel buildup which continues in the absence of fire (Agee 1974, Dodge 1972).

Coastal Forests

Although some fire ecology investigations have been carried out in the coastal forests of southern British Columbia, as well as Washington and Oregon, little or no such specific work has been undertaken in the north coast forests. This is partially explained by the fact that fire seems to be a very rare occurrence in this particular region. Harris and Farr (1974) noted that while there are significant areas of even-aged stands on the Alaska panhandle which apparently owe their origin to fire, the bulk of the forests are uneven-aged. Age class structure suggests that extensive fires burned between 1804 and 1824, in 1734, and during 1664. Since 1900 few individual fires have burned more than 40 ha. Extended periods of drought occurred in southeast Alaska during the summers of 1958, 1968, and 1971 but only 2 out of the 70 fires which broke out in these years were not man-caused.

An examination of the Provincial Fire Atlas of the Ministry of Forests in Victoria revealed that lightning-caused fires have been most uncommon on the north coast, at least during the period of record (1940 - 1982). This record, however, may overlook certain fires which burned undetected and were extinguished naturally. Only four lightning-caused fires were found for the entire Queen Charlotte Islands system and these never exceeded 0.1 ha in size, albeit perhaps in response to fire suppression action. Fire size and the possible intervention of man are secondary considerations - the indication is that due to one or more factors such as lightning frequency, regional climate, the characteristics of lightning storms, or vegetation (with respect to propensity to burn), the incidence of lightning-caused fires is minimal.

Expanding the area in question to include the mainland west of a rough boundary defined by the heads of the coastal fiords and the lower reaches of

the Skeena River added 63 lightning-caused fires for the same period. Of these, 65.0% were less than 0.1 ha in size, 17.5% between 0.2 and 5.0 ha, 6.4% between 5.1 and 50.0 ha, 4.7% between 50.1 and 500 ha, and 6.4% were greater than 500 ha. With some allowance for fire suppression activities, the figures indicate a greater incidence of lightning fire starts on the inner mainland coast as well as the potential for a proportion of these fires to attain a reasonable size.

Of the three biogeoclimatic zones on the north coast, the Coastal - Cedars - Pine - Hemlock (CCPH); the Coastal Western Hemlock (CWH); and the Mountain Hemlock (MH); the CCPH zone appears to have little or no recent fire history. This zone occupies a narrow low elevation belt on the Queen Charlotte Islands and the mainland coast, is never more than 25 km from the ocean, and possesses a cool and wet climate.* The climatic climax forest in the CCPH zone consists of western redcedar, yellow cedar, western hemlock, shore pine, and mountain hemlock. Sitka spruce, Pacific silver fir, and red alder are also found. The predominance of these shade tolerant and fire sensitive species coupled with the climatic characteristics of the zone suggests that fire here is rare.

The other biogeoclimatic zones of the north coast extending up to and east of the heads of the coastal fiords (CWH) and at higher elevations (MH) have a greater incidence of lightning-caused fires, as previously described. Indeed, lightning-caused fires are locally abundant in the CWH, such as between Terrace and Kitimat as well as just east of Bella Coola. Common forest trees in the CWH are the climax western hemlock and Pacific silver fir, also present are Douglas-fir, western redcedar, and Sitka spruce. These species are adapted to perpetuation subject to a fire regime characterized by long return interval stand-replacement crown fires (Lotan et al. 1981), fitting into fire regimes 5 or 6.

*Zone descriptions are from Jones and Annas (1978) and material on file with the Research Branch of the Ministry of Forests, Victoria, B.C. Climax species refer to those on zonal sites.

Fire frequency in the western hemlock forests of the Pacific Northwest was estimated to be greater than 150 years (Martin et al. 1976) although there are abundant stands of 400 years of age or more, suggesting that the historical average fire-free interval was in the order of a few centuries (Lotan et al. 1981). In southeast Alaska, secondary forest succession following disturbance by fire in an existing western hemlock and Sitka spruce stand generally begins with a shrub stage of short duration. Tree seedlings become established at about the same time but are inconspicuous until 8 or 10 years later at which time the western hemlock and Sitka spruce overtop the shrub layer. The resulting forest stand will remain even-aged until it reaches 300 years of age, when it will gradually change to an uneven-aged condition. As succession proceeds, western hemlock is favoured over the less tolerant Sitka spruce until a climax condition develops (Harris and Farr 1974). With more severe site disturbance (organic matter removal and soil exposure) early successional species such as alder and willow may be favoured but they too will eventually be replaced by the tolerant conifers.

In the coastal western hemlock region of the Pacific Northwest states post-fire succession begins with a herb-dominated stage which lasts about five years, followed by a shrub stage (Fahnestock 1977). Douglas-fir and alder may be aggressive pioneers but all species of the pre-fire stand may be represented on the burn site if a seed source is nearby. Douglas-fir which has seeded into burned sites will survive for 700 years or more while the spruce and western hemlock (which may also have become established at the same time) are slower growing, but being tolerant of shade they will become dominant in time, the western hemlock especially increasing in abundance (Lotan et al. 1981). Seedlings of western hemlock and western redcedar may become established under a young canopy of Douglas-fir which provides partial shade (Weaver 1974) or, alternatively, the breakup of a Douglas-fir stand at age 100 to 150 years may allow the invasion of western hemlock (Franklin and Dyrness 1973). The main point is that the latter species will generally be able to reproduce under the existing canopy while the relatively

shade-intolerant Douglas-fir will drop out. In this instance Douglas-fir stands represent a fire-induced subclimax type, seral to the climax western hemlock, Pacific silver fir, and western redcedar (Franklin et al. 1981).

Schmidt (1960) felt that the lower incidence of forest fires on the north coast was responsible for the fact that Douglas-fir is not found north of Kemano, while western redcedar continues north for another 480 km and western hemlock for another 1 100 km. The latter two species can colonize burned sites as well as reproducing under the shade of a canopy, while the pioneer Douglas-fir is put at a disadvantage where the incidence of fire and therefore suitable germination sites is low. Klinka et al. (1979) found Douglas-fir in the drier variant of the CWH on Vancouver Island but its distribution was considerably reduced in the wetter maritime CWH subzone, presumably due to special habits or the lack of fire history.

That coastal Douglas-fir types are fire-induced seral stands has long been recognized. Judd (1915) described the changes which take place in the continued absence of fire - the Douglas-fir weaken and die, to be replaced by western hemlock, western redcedar, true firs, and sometimes Sitka spruce. Conventional wisdom has held that these seral Douglas-fir stands were quite even-aged. However, recent studies have determined that the range in ages of the dominant Douglas-firs may approach 200 years, indicating a lengthy regeneration period (Franklin and Waring 1980). This extended period may be due to a lack of seed source, vegetation competition, or multiple disturbances (partial reburns of young stands).

Above the CCPH and the CWH zones is found the Mountain Hemlock (MH) biogeoclimatic zone. The MH is subalpine in nature with a short growing season and high snowfall. Lower elevation forests are continuous but give way to more open stands at higher elevations. Common forest trees are mountain hemlock, Pacific silver fir, and yellow cedar. Fire-related studies in the MH zone have been few. Brooke et al. (1970) found charcoal layers in one-third

of 140 soil pits in the southwestern B.C. portion of the zone. Age class analysis of the trees established where charcoal was found suggested fire dates in the early 1600's and late 1700's although forest regeneration may not have immediately followed a fire due to unfavourable microclimatic conditions.

Agee and Huff (1980), studying the Hoh fire on the Olympic Peninsula of Washington state, found significant differences in fire behaviour between the subalpine Pacific silver fir-mountain hemlock and the montane western hemlock-Douglas-fir type below it. While the respective ratios of burned to unburned area were roughly equivalent, more than half of the subalpine type experienced a crown fire versus only 10% of the montane forest.

Periodic and severe drought was thought to be responsible for previous fires on the study site and these dated to 1473, 1488, and 1514. Other major forest disturbance factors in this zone of steep topography include wind, snow avalanches, and debris avalanches and torrents. In contrast to abundant initial forest tree regeneration in the montane type, the subalpine MH zone supported only 480 seedlings per ha, apparently due to a lack of seed source (Agee and Huff 1980).

Vegetation development following fire in the MH zone is often slow. The successional sequence of forest tree species varies geographically (Lotan et al. 1981) although the climax species present usually function as pioneers (Fahnestock 1977). Repeated burning in the MH zone of the Pacific Northwest states has led to the establishment of herb and shrub dominated communities (Franklin and Dyrness 1973). Fire may be a factor in creating and maintaining subalpine meadows (Kuramoto 1968) although disagreement exists as to whether the presence of regenerating trees in a meadow community is due to fire exclusion (Griggs 1938) or climatic change (Franklin et al. 1971).

## Interior Forests

The interior forests of the Prince Rupert Forest Region contain three biogeoclimatic zones, the Interior Cedar - Hemlock (ICH); the Engelmann Spruce - Subalpine Fir (ESSF); and the Sub-Boreal Spruce (SBS). The Provincial Fire Atlas indicates that lightning-caused fires are common throughout these zones.

The ICH occupies the lower to middle elevations of the Hazelton and Skeena Mountains, the Nass River basin, and the lower Iskut River valley. Winters are cool and wet, while summers are warm and dry. Climax stands consist of a spruce hybrid (white x Sitka), western hemlock, western redcedar, and subalpine fir. Fire-originated seral stands of lodgepole pine, trembling aspen, and birch may also be found.

A forest regeneration plot established by the author during 1981 in the 31,600 ha ISKUT burn of 1958 revealed sparse cover of lodgepole pine (75 stems per ha), subalpine fir (50 sph), and rare individuals of spruce (hybrid) and western hemlock. Some trembling aspen and green alder were found as well but the bulk of the vegetation consisted of Scouler willow (30% cover), oval-leaved blueberry (70%), various herbs (43%), and mosses (17%). Ages of the young conifers ranged from 22 to 5 years, indicating that seed input from residual sources has been gradual. Seedling development will likely continue given a seed source, seedbed, and suitable conditions for survival and growth. Although establishing together, the seral lodgepole pine and trembling aspen will in time give way to the more tolerant conifers.

In the similar inland maritime forests of the northern Rocky Mountains succession in the absence of fire leads to western redcedar and western hemlock dominated forests (Lotan *et al.* 1981). Fire-dependent seral species in these forests such as lodgepole pine, western larch, western white pine, and Douglas-fir are common due to past fires. Western redcedar in Glacier National Park (Montana) enters pioneer communities early in succession because

of its lightweight easily-disseminated seeds, and seedlings which are less shade tolerant than those of western hemlock. The latter species is capable of invading existing communites and developing under dense shade (Habeck and Mutch 1973).

In the North Cascades National Park of Washington state, post-fire germination of both western redcedar and western hemlock on some sites was found to be more abundant than the expected seral Douglas-fir (Miller and Miller 1976). In the maritime-influenced inland forests of Montana, the climax western hemlock and western redcedar usually regenerate on burned sites along with and beneath the seral species. Due to the longevity of the seral species (Douglas-fir, spruce, lodgepole pine, and paper birch) the climax species do not assume dominance for several hundred years (Pfister et al. 1977). Early succesional stages may be dominantly herbs such as fireweed, or shrubfields of willow, raspberry, and blueberries and these may persist with short intervals between fires (Arno 1980).

Severe stand-replacement fires have occurred at intervals of 150 to more than 500 years (Davis et al. 1980) and are made possible by periodic and extreme summer drought (Arno 1980). In addition, evidence from northern Idaho suggests that fire behaviour has ranged from low intensity surface fires to high intensity crown fires (Arno and Davis 1980). This variable fire behaviour creates a patchwork pattern of complete stand kill, partial kill, and unburned forest.

The Engelmann Spruce - Subalpine Fir (ESSF) biogeoclimatic zone is a high elevation zone located below the Alpine Tundra zone in much of the B.C interior. The climate is cold, dry, and continental, resulting in a short growing season and severe winters. Engelmann spruce (or an Engelmann x white hybrid) and subalpine fir are the dominant climax trees. Lodgepole pine is present as a seral species, becoming more abundant in drier locales. At upper elevations the forest takes on an open parkland appearance, with the distribution of trees related to available moisture supply.

Fire size in the ESSF may be limited by topography or fuel discontinuities such as rock ridges, scree slopes, or less flammable vegetation (eg. wet meadows). Surface fires and more intense crown fires are both possible (Pfister et al. 1977, Arno 1980) and fire may originate in the zone itself or be driven into it from lower elevations. Well-established fires can travel through the ESSF and timberline zones and have been known to cross the Continental Divide (Habeck and Mutch 1973). The interval between fires probably averages 150 years or more (Arno 1980) and can significantly differ between aspects (Hawkes 1979).

In the spruce and true fir forests of the northern Rocky Mountains successional development in the absence of fire favours the true firs over spruce and lodgepole pine. On the other hand, fire favours the serotinous lodgepole pine at the expense of the fire-sensitive true firs and spruces (Lotan et al. 1981). On dry sites in the ESSF of the Cariboo Forest Region lodgepole pine may be present in the climax community but is generally seral (Annas and Coupe 1979).

Post-fire vegetation development may begin with a herb or shrub stage (Fahnestock 1977). Engelmann spruce and subalpine fir may colonize a burned site directly or there may be an intermediate successional stage of lodgepole pine (Loope 1971). A mixture of all species at once is also possible (Habeck and Mutch 1973). Succession without fire will lead from (1) non-forest to (2) lodgepole pine; then to a (3) transition lodgepole pine-Engelmann spruce-subalpine fir stand; and finally to climax (4) Engelmann spruce-subalpine fir. Subsequent fires in types (2), (3), or (4) can put the community back to its predecessor or perhaps from type (4) to type (2) or (1) (Reese et al. 1975). Diagramatically this can be shown as:

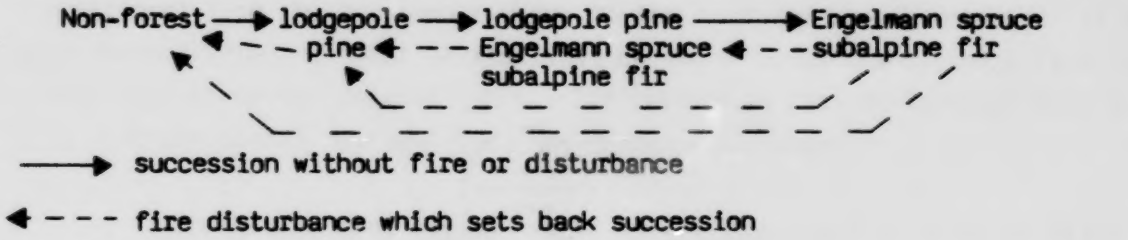


Figure 1. Successional pathways in the spruce-fir zone (Modified from Reese et al. 1975).

Day (1972) found the communities described above in the ESSF of southern Alberta but added a further stage, a low vigour forest where subalpine fir dominates in an uneven- to all-aged subalpine fir-Engelmann spruce stand. It was concluded that the old growth Engelmann spruce-subalpine fir type is not a self-perpetuating climax type but rather is fire-dependent; the continued absence of fire will result in its disappearance. This was corroborated by Loope and Gruell (1973) who noted that subalpine fir seedlings are 10 to 20 times as abundant as those of Engelmann spruce in old growth stands. However, such stands are predisposed to fire because of heavy fuel buildups and no pure subalpine fir stands could be found due to the historical intervention of fire.

Davis et al. (1980) presented a similar version of succession in the ESSF, shown here as Figure 2. Lodgepole pine is seral and favoured by frequent fires while the climax types are subalpine fir (ABLA) and Engelmann spruce (PICEA). Recovery processes in this zone are extremely slow such that frequent fire disturbance is not needed to maintain a diversity of types and age classes (Habeck and Mutch 1973). Short interval "reburns" at higher elevations are uncommon due to the discontinuous nature of the fuels (Gabriel 1976).

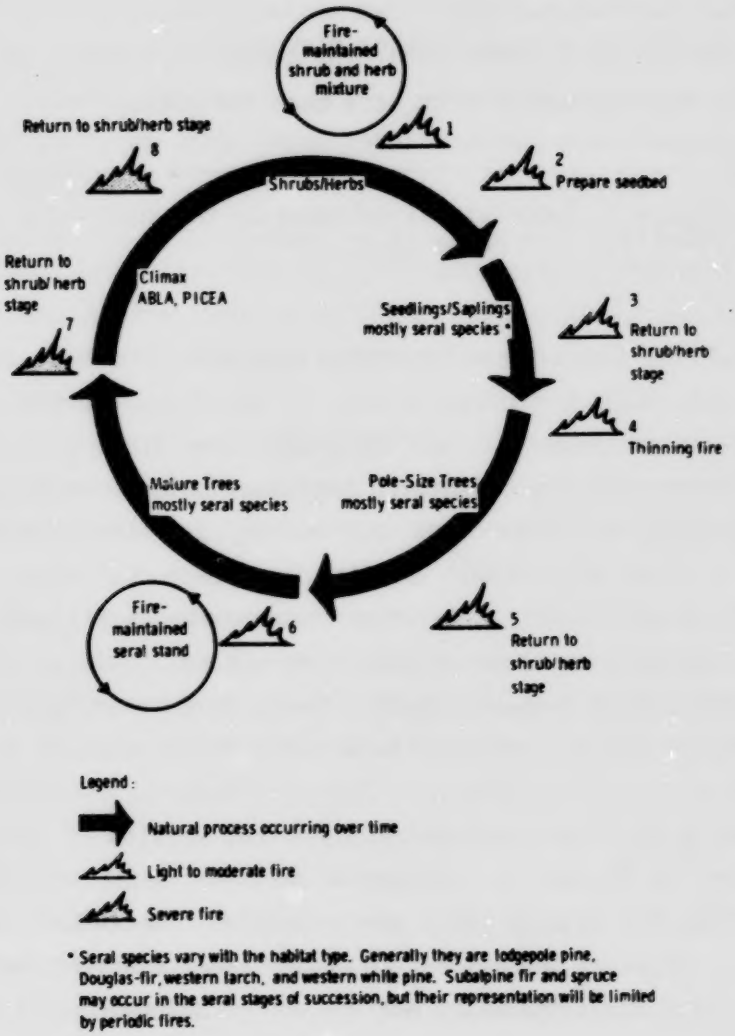
Fire-maintained shrub and herb mixture
1
2
Prepare seedbed
3
Return to shrub/herb stage
4
Thinning fire
Pole-Size Trees mostly seral species
5
Return to shrub/herb stage
Fire-maintained seral stand
6
Mature Trees mostly seral species
Climax ABLA, PICEA
7
Return to shrub/herb stage
8
Return to shrub/herb stage
Shrubs/Herbs
Seedlings/Saplings mostly seral species *
Legend:
Natural process occurring over time
Light to moderate fire
Severe fire
* Seral species vary with the habitat type. Generally they are lodgepole pine, Douglas-fir, western larch, and western white pine. Subalpine fir and spruce may occur in the seral stages of succession, but their representation will be limited by periodic fires.

Figure 2. Forest succession in the ESSF: fire-maintained lodgepole pine stands in spruce and subalpine fir climax series habitat types (from Davis et al. 1980).

The Sub-Boreal Spruce (SBS) zone is located in the central interior and is transitional from the southern montane to the northern boreal forests. It is also found in the northwest of the province where it is transitional from the boreal forests to the coastal types. The climate is less continental than the more northern boreal zone and the growing season is longer.

The dominant tree species are hybrid spruce (Engelmann x white or Sitka x white), white spruce, and subalpine fir. Lodgepole pine and trembling aspen are pioneers following fires, paper birch has a like role on moister sites. Advance growth of spruce and subalpine fir is usually present under lodgepole pine and trembling aspen stands, indicating an eventual species conversion as succession proceeds (Eis 1963, Revel 1972). Subalpine fir and white spruce exhibit their best growth on seepage and alluvial sites. Black spruce may also occur in poorly drained areas.

Forest fires have been common in the central interior portion of the SBS (Revel 1972) and have influenced the northwestern SBS as well, although the outward effects are less obvious as fire is likely rarer there due to a generally greater precipitation. Garman (1929) studied natural regeneration following fires in standing timber in the SBS east of Prince George. He found fireweed, willows, birch, and trembling aspen on most burn sites with lodgepole pine prominent on drier sites. It was felt that at least one generation of lodgepole pine would be needed to enable "building of the soil" and permit the invasion of later successional species. The decline in vigour and loss of the seral species such as trembling aspen was noted in stands of 60 to 70 years of age.

In the spruce-true fir type, a comparison of sites burned 4 to 22 years previous with those burned 37 to 75 years previous showed an increase in numbers of Engelmann spruce and true fir and a decline in the numbers of lodgepole pine, Douglas-fir, black cottonwood, trembling aspen, and birch (Garman 1929). Higher frequencies of certain herbaceous plants were found in

the older burns and some opportunists such as fireweed had dropped out entirely in the older communities. The density and species of tree reproduction on burns was found to be related to soil moisture conditions after fire and the subsequent availability of seed. Eis (1963) also reported a dependence of white spruce and subalpine fir seedlings on available soil moisture in the SBS. On undisturbed humus seedbeds neither species survived; mortality was heavy on exposed dry sites; and survival best on moist mineral soils. Thus, the exposure of mineral soil after fire represents a preferred seedbed but microclimatic conditions determine the levels of tree seedling survival and growth.

Possible successional development in the SBS following logging and burning was presented by Annas and Coupe (1979), reproduced here as Figure 3.

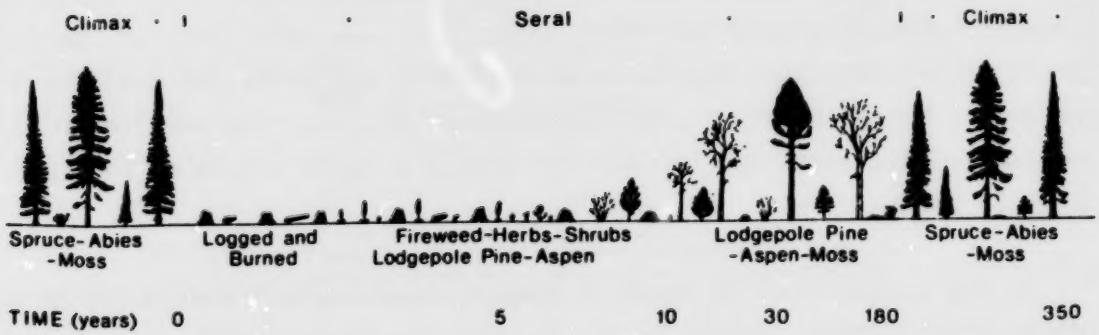


Figure 3. Possible succesional development in the Sub-Boreal Spruce Zone.

## Northern Forests

The northern forests of the Prince Rupert Forest Region are considered here to contain two biogeoclimatic zones of interest - the Boreal White and Black Spruce (BWBS) and the Spruce - Willow - Birch (SWB). A lightning fire regime has historically influenced vegetation development in both zones. Stand-replacement crown fires are the norm although surface fires have been common in some locales as a result of prescribed burning. Evidence of surface fires may also be found outside the perimeter of stand-replacement type burns where the fire's behaviour was moderated, affecting only the surface fuels.

The BWBS is found roughly above $57^{O}$ N Latitude and up to elevations of 1 000 m. The climate is northern continental with long cold winters and hence a short growing season. This zone is vegetationally very diverse and contains white spruce, lodgepole pine, trembling aspen, subalpine fir, paper birch, balsam poplar, black spruce, and tamarack. Hazardous fire weather conditions are encouraged by lengthy summer days which result in a long diurnal drying period as well as by extended periods of low precipitation and relative humidity. The forest stands themselves are often highly flammable due to an abundance of flammable lichens (Cladina spp.), and surface vegetation (eg. Labrador tea), and dense tree crowns extending to the forest floor (eg. black spruce).

That fire represents the major disturbance force in the boreal forest has long been recognized (Lutz 1955, Rowe and Scotter 1973, Viereck 1973, Kelsall et al. 1977, Viereck and Schandelmeier 1980). With infrequent stand-replacement type crown fires and tree species which are fire sensitive and generally killed, forest regeneration depends upon on-site or off-site adaptations. On-site adaptations are vegetative reproduction (trembling aspen, birch, balsam poplar); cone serotiny (lodgepole pine); and semi-serotiny (black spruce). In cases such as these the individuals or their above-ground components may be killed by fire but the species reestablishes.

Off-site adaptations consist of seed dispersal from remnant stands within the burn or from adjacent stands (white spruce, subalpine fir, lodgepole pine, tamarack, trembling aspen, birch, and balsam poplar). Establishment and survival of germinants from seed is dependent upon a suitable seedbed, subsequent favourable microclimatic conditions, and freedom from excessive vegetative competition. If the first two conditions are not met, those species capable of vegetative reproduction will be favoured. Lotan et al. (1981) summarized the reproductive habits of the major boreal forest tree and shrub species.

The interval between fires on a given site can be as low as 20 to 30 years and the absence of stands much older than 200 years attests to the prevalence of fire. Pure stands of lodgepole pine and black spruce are essentially recycled by fire although a short interval between fires will lead to a more open subsequent stand, depending upon how many trees are sexually mature at the time of the fire. When established together, the lodgepole pine exhibits greater initial height growth and yet will eventually die out to be replaced by the more shade tolerant black spruce (which can also reproduce vegetatively by layering of the lower branches). Trembling aspen may also be present and is seral to the black spruce as well. On wetter sites tamarack may occur and requires an off-site seed source.

White spruce, lodgepole pine, and trembling aspen commonly colonize burned sites together, the latter two species overtopping the white spruce but eventually dying out to leave a pure or nearly pure stand of white spruce. Subalpine fir may later invade the stand and become codominant or dominant in time, perhaps to the total exclusion of white spruce. White spruce and trembling aspen exhibit a marked difference in initial growth rates - the trembling aspen forms an overstory to the white spruce until about age 100 when the white spruce overtops the trembling aspen which then soon dies out. Regeneration of white spruce beneath the canopy is generally restricted to decayed wood substrates. Subalpine fir may enter these stands as well.

Subalpine fir also exhibits pioneer characteristics and is often found in company with lodgepole pine. The latter species again overtops the true fir but eventually the stand will develop into pure shade-tolerant subalpine fir, unless fire intervenes. Alternatively, subalpine fir may enter an established lodgepole pine stand in the order of several decades after the fire which led to the initial stand.

Natural regeneration after fires in the BWBS is generally prompt - many stands show an age range of only 10 to 15 years, sometimes up to 20. However, where initial restocking levels are low and seed source and seedbed conditions continue to be favourable, recruitment may continue for several decades. Shifts in species abundance may take place such as where a stand of white spruce, subalpine fir, and lodgepole pine experiences a crown fire. The lodgepole pine will have an on-site advantage (being serotinous) while the other two species will depend upon an off-site seed source. Mixed white and black spruce stands are locally common, in this case black spruce would have an on-site advantage being semi-serotinous and maturing before the white spruce.

Vegetation development following fire is complicated by a number of factors. Shown in Figure 4 are possible outcomes of a fire in a trembling aspen stand and subsequent development. Repeated burning in the aspen types of the lower Stikine River valley, for example, has promoted trembling aspen at the expense of white spruce. Short intervals between fires in any type, if continued, will encourage lesser vegetation such as shrub and herbaceous species.

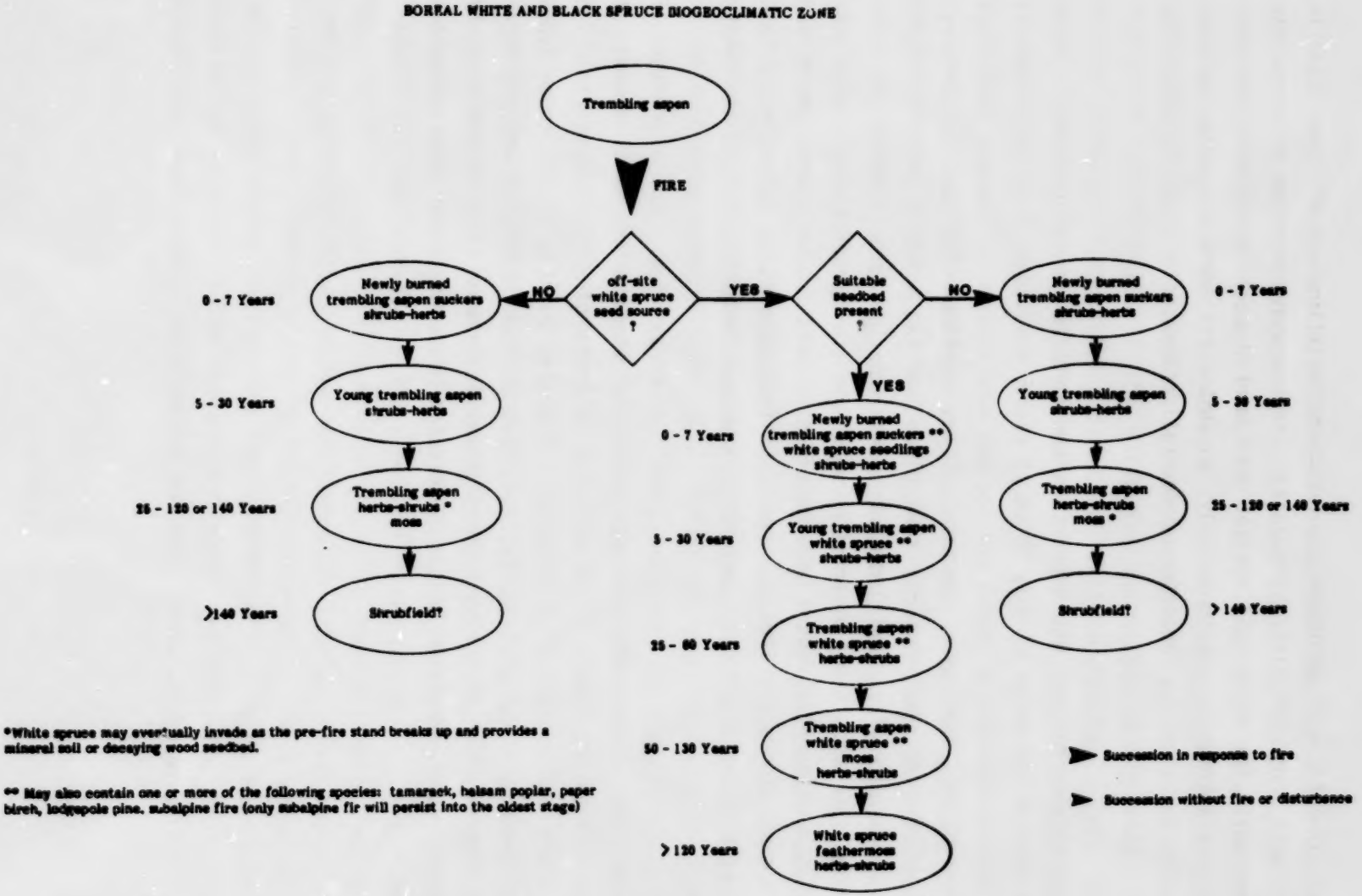
BOREAL WHITE AND BLACK SPRUCE BIOGEOCLIMATIC ZONE
Trembling aspen
FIRE
off-site white spruce seed source ?
NO
YES
Suitable seedbed present ?
NO
YES
0 - 7 Years
Newly burned trembling aspen suckers shrubs-herbs
5 - 30 Years
Young trembling aspen shrubs-herbs
25 - 120 or 140 Years
Trembling aspen herbs-shrubs * moss
>140 Years
Shrubfield?
0 - 7 Years
Newly burned trembling aspen suckers ** white spruce seedlings shrubs-herbs
5 - 30 Years
Young trembling aspen white spruce ** shrubs-herbs
25 - 80 Years
Trembling aspen white spruce ** herbs-shrubs
50 - 130 Years
Trembling aspen white spruce ** moss herbs-shrubs
>130 Years
White spruce feathermoss herbs-shrubs
0 - 7 Years
Newly burned trembling aspen suckers shrubs-herbs
5 - 30 Years
Young trembling aspen shrubs-herbs
25 - 120 or 140 Years
Trembling aspen herbs-shrubs moss *
>140 Years
Shrubfield?
*White spruce may eventually invade as the pre-fire stand breaks up and provides a mineral soil or decaying wood seedbed.
** May also contain one or more of the following species: tamarack, balsam poplar, paper birch, lodgepole pine, subalpine fire (only subalpine fir will persist into the oldest stage)
Succession in response to fire
Succession without fire or disturbance

Figure 4. Succesional pathways following fire in trembling aspen.

The Spruce - Willow - Birch (SWB) biogeoclimatic zone is the most northerly subalpine type in the province, occurring above the BWBS and below the Alpine Tundra zones. The climate is interior subalpine, with long cold winters and short cool summers. The zone obtains its name from the most common plant species - white spruce, various willows, and bog birch. The lower elevations consist mainly of a semi-open forest of white spruce with some subalpine fir. On higher slopes subalpine fir becomes predominant, sometimes as a function of aspect. Lodgepole pine, trembling aspen, and black spruce are minor components but may be locally abundant.

Fires have been less frequent and less extensive in the SWB although charcoal in the soil profile can usually be found, attesting to fire's presence. Large fires are possible as indicated by the upper Stikine/Chukachida area, although fire spread is probably limited in most cases by topography and fuel discontinuities. Fires may originate in the SWB or be driven into it from the lower slopes. Surface fires have occurred in the area east of Atlin although these were likely man-caused. Prescribed burning is locally common, such as in the Kechika drainage.

The initial stages of post-fire succession are dominated by herb and shrub species. Where present, lodgepole pine and trembling aspen form an overstory to white spruce and subalpine fir but eventually are replaced by one or both of the latter two species. Trembling aspen is the first to drop out, followed by lodgepole pine at a stand age of between 300 and 400 years. Once again subalpine fir can function as a pioneer and will become more plentiful with time, especially by vegetative reproduction (layering of the lower branches). Upper elevation stands may be pure subalpine fir but this likely reflects the inability of white spruce to grow there rather than its loss through succession.

Regeneration periods are lengthy - commonly 70 years or more. The developing stands may begin with a post-fire flush of germinants but become all-aged in time. Extensive burned areas mean that forest reestablishment

will be a long process, as it will also be at high elevations. However, clumps of fire survivors are often found within burns and these will act as seed sources. The SWB is similar to the ESSF with respect to fire in that fire is rarer and recovery processes are longer. One is more likely to find older stands in the SWB than in the BWBS, testifying to the longer return interval between fires.

Natural and Prescribed Fire

As previously described, natural fire has played a varied role in the different environments of the Prince Rupert Forest Region, as represented by the biogeoclimatic zones. Fire has been rare in some zones, common in others, and the major disturbance factor in some. A knowledge of fire history and the ecological effects of fire raises the question of how fire might be used to imitate or improve upon natural processes. The major objectives of prescribed fire use have been to consume organic matter such as logging slash; to control unwanted insects, diseases, and plants; and to manipulate vegetation succession (Fahnestock 1973).

While man's forest harvesting and site treatment operations attempt to duplicate natural forest renewal forces such as fire, there are important distinctions to be made between the two operations. These were outlined by DeByle (1976) (see p. 27).

When man's artificial practices most closely emulate those of nature, the fewer the long term man-induced impacts that will result. Conversely, the imposition of 'unnatural' processes into ecosystems will result in greater site disturbance (DeByle 1976). While the majority of the forests in the Prince Rupert Forest Region have historically experienced long return interval stand-replacement fires or perhaps very little fire, if any, the opportunity exists for the judicious application of prescribed fire to achieve specific

Table 2. Comparison of wildfire effects with clearcutting and debris disposal.

| Factor | Wildfire | Clearcutting and debris disposal |
|---|---|---|
| Cycle length | Variable within broad limits. | Set to rotation age. |
| Area affected | From small patches to thousands of hectares. | Small and set within relatively narrow limits. |
| Season | When driest, usually late summer. | All seasons, with prescribed burning only when controllable. |
| Intensity of fire | Intense over long cycles, low intensity at short intervals. May be intense in crowns with low intensity at forest floor. | If used, usually of lower intensity for broadcast debris; or, with piled debris, from extreme in piles to nonexistent between. |
| Prior soil condition | Dry surface organic horizon, usually over dry mineral soil. Often results in pronounced heating of mineral soil. | Variable water content, depending on season of cutting; burning usually done over a wet soil mantle; virtually no mineral soil heating, except under burned piles, where it is severe. |
| Resulting soil | Blackened, and frequently burned to bare mineral soil. | Depends upon debris treatment:<br>1. Disturbed duff and understory due to harvesting; soil covered with limbs, tops, and culls.<br>2. Same as (1) but blackened after broadcast burning; mineral soil exposed on 5% to 25% of area.<br>3. Machine piling of debris bares mineral soil on the 75% of area between piles. Surface organic horizon often scraped away or mixed into mineral soil. |
| Physical disturbance of mineral soil | No direct disturbance. | Logging roads, landings, and skid trails, often followed by dozer piling of debris cause soil disturbance. |
| Forest stand | Trees remain standing as live, dying, or dead; often a viable seed crop is in canopy. | Boles removed; limbs and tops remain on ground to decay, to be piled and burned, or to burn in place. |
| Regeneration | Natural, with seral brush or herbaceous species sometimes preceding conifers by many years. | Natural, often later thinned; seeded or planted if natural regeneration is unsatisfactory. |

objectives. This is predicated upon a knowledge of the results desired; the proper treatment required to achieve those results; and if the treatment called for is prescribed fire - can it be applied with the level of sophistication necessary to carry out the treatment successfully and with minimal adverse effect?

Summary

Naturally occurring fires have long influenced forested ecosystems to a greater or lesser degree. Through a variety of effects fire has determined the distribution of vegetative species on the landscape, producing a mix of successional stages. Where fire has been common, many plants are fire-tolerant, fire-adapted, or fire-dependent. Where fire has been present but rare, plants are generally fire-sensitive but may still be able to take part in the initial stages of succession following fire.

The fire regime which characterizes particular ecosystems is defined by fire type and intensity, fire size, and return interval (frequency). Fire frequency and intensity in turn are related to climate, topography, and vegetation (fuels). Post-fire vegetation development is dependent upon the pre-fire vegetation and its state of development; the season of the burn; fire behaviour and intensity; the depth of burn (degree of removal of surficial organic matter); fire size; off-site vegetation; physical site characteristics; and post-fire environmental conditions.

Fire has likely been very rare in the CCPH zone and infrequent in the CWH. Periodic and severe drought may be a prerequisite to fire in the MH zone although the fire ecology of this type has received little study. Fires have been common in the ICH and SBS zones as evidenced by the abundance of fire-originated seral stands. The two subalpine zones, the ESSF and the SWB, have experienced relatively infrequent fire and share lengthy recovery periods

following disturbance. The BWBS zone appears to support the greatest natural role for fire of all the biogeoclimatic zones of the Prince Rupert Forest Region.

Common features shared by most of the zones are that fire, and especially frequent fire, favours vegetation species which are in some way fire-adapted. The continued absence of fire from a site will permit successional development to proceed in a direction which will include more shade-tolerant and generally fire-sensitive species. However, a significant number of these species are also capable of acting as pioneers on burned sites if conditions are favourable. Conversely, the continued application of fire to a site will push succession in the other direction and favour early successional and fire-adapted species.

Significant differences may exist between the natural fire regime and the application of prescribed fire by man for various purposes. Just as natural fires can be negative, neutral, or positive in relation to man's land management objectives; man's prescribed fires can be negative, neutral, or positive in relation to nature's objectives. The challenge to man is to apply the right kind of fire to the right site at the proper time to produce the desired results with minimal adverse impact on short term goals and long term ecosystem productivity.

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## List of Vegetation Species

### Lichens

| | |
|---|---|
| *Cladina* spp. | lichens |

### Herbs

| | |
|---|---|
| *Corydalis sempervirens* (L.) Pers. | pink corydalis |
| *Epilobium angustifolium* L. | fireweed |

### Shrubs

| | |
|---|---|
| *Betula glandulosa* Michx. | bog birch |
| *Ledum groenlandicum* Oeder | Labrador tea |
| *Rosa acicularis* Lindl. | wild rose |
| *Rubus idaeus* L. | red raspberry |
| *Salix scouleriana* Barratt | Scouler willow |
| *Vaccinium ovalifolium* Smith | oval leaved blueberry |
| *Viburnum edule* (Michx.) Raf. | high bush cranberry |

### Trees

| | |
|---|---|
| *Abies amabilis* (Dougl.) Forbes | Pacific silver fir |
| *Abies lasiocarpa* (Hook.) Nutt. | subalpine fir |
| *Alnus rubra* Bong. | red alder |
| *Alnus viridis* (Chaix) de C. | green alder |
| *Betula papyrifera* Marsh. | paper birch |
| *Larix laricina* (DuRoi) K.Koch | tamarack |
| *Chamaecyparis nootkatensis* (D. Don) Spach | yellow cedar |
| *Picea engelmannii* Parry | Engelmann spruce |
| *Picea glauca* (Moench) Voss | white spruce |
| *Picea mariana* (Mill) B.S.P. | black spruce |
| *Picea sitchensis* (Bong.) Carr | Sitka spruce |
| *Pinus contorta* var. *contorta* Dougl. | shore pine |
| *Pinus contorta* var. *latifolia* Engelm. | lodgepole pine |
| *Populus balsamifera* L. | balsam poplar |
| *Populus trichocarpa* T. & G. | black cottonwood |
| *Populus tremuloides* Michx. | trembling aspen |
| *Pseudotsuga menziesii* (Mirbel) | Douglas-fir |
| *Thuja plicata* Donn. | western redcedar |
| *Tsuga heterophylla* (Raf.) Sarg. | western hemlock |
| *Tsuga mertensiana* (Bong.) Carr. | mountain hemlock |

# IMPACT OF PRESCRIBED FIRE ON THE PRODUCTIVITY OF INTERIOR FORESTS

R.G. McMinn[1]

## INTRODUCTION

The impact of prescribed fire on forest productivity depends on the characteristics of the fire and on the type and condition of the ecosystem affected (Feller 1982, Kozlowski and Ahlgren 1974). Effects may be long term as well as short term. This discussion reviews factors considered to be relevant to interior forests, especially those of the Sub-Boreal Spruce Zone.

## FIRE SEVERITY AND PERIODICITY

### Severity

For a site to be severely affected by prescribed fire, the fire must have sufficient intensity and duration. Intensity may be defined as the rate of heat release per unit of ground surface area. Dry, fine fuels (dry twigs and branches) ignited during a period of low humidity release heat rapidly. Impact may, however, not be great in terms of surface organic matter reduction if duration is short, which occurs when a fire quickly moves on in the absence of larger fuels. Surface organic matter may be singed, with little else affected. If larger fuels ignite and sustain the fire in place, much of the surface organic matter may be burned. Amount of reduction is also dependent on other conditions such as moisture content of the surface organic matter. Severity of burning can be defined in terms of amount of surface organic matter consumed, degree of reddening and change in structure of mineral soil, and in the proportion of the site severely affected.

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## Periodicity

Even if a site is severly burned, that is most of the surface organic matter is consumed, there will be less impact on site productivity if such a fire occurs once in a thousand years rather than every fifty years on a dry site in a dry climate. Severe fires (consumption of all surface organic matter) at relatively short intervals could well be a factor limiting productivity of lodgepole pine stands in the Chilcotin. Even more frequent burning to keep fuel loading down can be useful in preventing less frequent but more damaging fire occuring at longer intervals when fuel loadings have built up. Preemptive fires are reported to be an option used in some Australian equcalyptus forests (Gill et al. 1981). Periodic burning is also reported to be an effective disease control during the grass stage of longleaf pine (Boyce 1961).

# ENVIRONMENTAL FACTORS

## Soil

How did the clay, silt, sand, gravel and boulder left by the glaciers of the last ice age and more recently river deposited alluvial silt, sand and gravel differ from the soils on which the productivity of our forests depends? An essential difference is the biological activity, the effects of plant roots and soil structure (Armson 1977). Water and nutrient holding capacity were increased and fine textured materials made permeable and penetrable. Fire impact on soil varies with differences in physical and chemical properties, some intrinsic to soil parent materials but many the product of biological activity since parent materials were laid down.

## Soil Organic Matter

Soil organic matter affects the productivity of forest soils in several ways. Organic matter is the chief source of nitrogen and may be an important source of other macro-nutrients (P, K, Ca) and of micro-nutrients depending on the mineralogy of the mineral material. Organic acids formed during decomposition of organic matter are important in weathering and release of nutrients from the mineral consituents of the soil. The colloidal nature of organic matter makes it a significant component of the exchange complex. The exhange complex retains nutrient ions, keeping them in the soil profile ready for uptake by roots rather then allowing them to be leached through the profile and "wasted" in runoff. This characteristic of soil organic matter is particularly important in coarse-textured soils (sands and gravels) which, unlike fine-textured soils, have low exchange capacity in the mineral soil and therefore low capacity to retain nutrients. The presence of soil organic matter is a major factor in the development of soil structure in fine-textured soils. Without structure, such soils would be impermeable to water and impenetrable by roots. Organic matter increases the water holding capacity of soils; in fine-textured soils by improving soil structure; in coarse-textured soils organic matter provides the main water holding mechanism. A layer of organic matter on the soil surface facilitates infiltration of rain so that soils may be readily rewetted after dry periods and runoff and erosion reduced. Removal of organic matter from the surface of fine-textured soils may result in fine pores becoming clogged, reducing infiltration rates.

Fire impact on soil organic matter differs according to its location in the soil profile and the amount accumulated. Grassland soils in adequately warm and moist climates accumulate and incorporate organic matter to considerable depths, as much as 50 cm below the soil surface. Such soils are relatively impervious to deleterious impact by fire because there is little surface organic matter to burn off and not enough fuel for severe burning. Incorporated organic matter below the soil surface is essentially unaffected by fire.

In forest soils the proportion of organic matter which remains above the mineral soil, and is therefore vulnerable to fire, varies with ecosystem association. In xeric, oligotrophic ecosystem associations (eg. SBS d/.02, Pine-Lichen ecosystem association), production of organic matter is low and most remains on the soil surface as L and F layers. Fire can readily consume this surface organic matter, perpetuating unproductiveness. Organic matter in the Bm (mineral soil horizon) would be unaffected, but there is little to start with in xeric, oligotrophic soils.

Toward the upper end of the moisture and fertility scale in the Subalpine Fir Subzone of the SBS Zone, the Ah of soils in the fine textured phase of the Oakfern ecosystem association (SBSe/.07(b)) constitutes a considerable proportion of the organic matter present. Such incorporated organic matter is not readily destroyed by fire. Therefore, fire can be used for silvicultural objectives such as planter access or competing vegetation control with little probability of long term negative impact on productivity. Deleterious reduction of organic matter is unlikely to occur in wetter ecosystems such as SBSd or e/09 (Horsetail ecosystem associations) although burning opportunities may be limited by wetness.

Soil Texture

Interactions between fire and soil texture are often indirect through impact on soil organic matter. In fine-textured soils in dry climates (eg. Vanderhoof clay: SBSd/07 Bunchberry-Moss ecosystem association) rooting is confined to uppermost horizons because only surface organic matter and uppermost mineral soil horizons modified by incorporation of organic matter have sufficiently penetrable structure for extensive rooting. Organic matter production is limited by lack of moisture (dry climate, shallow rooting depth). Since severe burning may occur in dry climates because surface organic matter can become quite dry, reduction of organic matter can be considerable. Reduction of organic matter can have a long term deleterious effect on forest productivity because production of new organic matter is slow

in dry sites made even drier by reduction in effective moisture storage capacity and rooting depth. Short term beneficial effect, through release of nutrients from burnt surface organic matter would probably be more than counterbalanced by reduced moisture availability. Soil temperature increases might be greater than optimal, or, if potentially beneficial, negated by lack of moisture.

Short term impact of fire on moister fine-textured soils, (eg. SBSe/08(b) Devil's club ecosystem association, fine textured phase) on the other hand, is likely to be favourable. Nutrients released by burning slash and surface organic matter (except for those volatiiized) will be retained for recycling by plants by the exchange complex of unburned incorporated organic matter and clay minerals. Since moisture is not limiting, rooting depth has not been reduced and soil temperatures are likely to have been beneficially increased, short term effect is likely to be accelerated growth. As short term benefits diminish, the productivity of the ecosystem is likely to return to its previous level. Nutrients lost by volatilization during burning will probably not impose significant limitations on the productivity of fertile sites, or they can be replaced by weathering of mineral soil particles and recycling from the organic matter remaining, following the fire.

Burning on coarse-textured soils (eg. SBSd/03 Pine-Lichen-Moss ecosystem association) as noted previously is likely to have deleterious effects because reduction in organic matter reduces moisture storage capacity and nutrient capital.

Impact of organic matter reduction would be less severe on moister, coarse-texured soils, such as deep gravels (SBSe/04 Submesic Bunchberry-Moss ecosystem association) because greater availability of moisture would allow quicker recovery of organic matter accumulations. Short term effects are still likely to be negative because destruction of surface organic matter would reduce nutrients and moisture storage capacity. Seasonal moisture shortages can occur in coarse textured soils not continuously supplied with moisture. When coarse-textured soils are supplied with seepage moisture, a

more productive ecosystem association would be present (eg. SBSe/08(a) Devil's club ecosystem association, coarse textured phase) and fire impact would be positive or marginally negative at worst.

Soil Temperature

Experimental results suggest that soil temperatures as high as 25° C may be optimum for growth of spruce seedlings (Dobbs and McMinn 1977). Field measurements east of Prince George in the Sub-Boreal Spruce Zone indicate that maximum temperatures at 5 cm below the soil surface in untreated clearcuts rarely exceed 15° C. Reduction of insulating surface organic matter by fire should therefore beneficially affect growth of planted seedlings in ecosystem associations where reduction of surface organic matter does not otherwise have deleterious effects (eg. SBSd/08, /09; SBSe/07, /08, /09).

Whether planting should be delayed on burned sites until lesser vegetation has reestablished some shade seems doubtful. Shading vegetation on dry sites uses soil moisture needed for seedling growth. The benefits of shade may consequently be outweighed by the disbenefits of moisture depletion. In moister ecosystems, vegetation encroachment may smother seedlings if planting is delayed. A critical appraisal of relative benefits and disbenefits of immediate or delayed planting for each ecosystem association for which fire is appropriate seems called for.

Soil Nutrients

Organic matter (surface and incorporated) and residues (cull logs and logging slash) represent a major proportion of the nutrient capital of many sites. When these materials are burned, the total quantity of some elements (N, P, S) is redcuced by volatilization. The availability of some of these elements (N and P) and exchangeable cations (K, Ca, Mg) is increased because they are changed into more soluble forms in the ash. Increased availability

may result in an immediate flush of growth. Increased availability may also result in nutrient depletion because in their more available form these elements may be leached from the profile. Leaching losses will be greatest in coarse-textured soils and where growth of vegetation is sparse following fire. With sufficient vegetation regrowth on fine textured soils having adequate incorporated organic matter, leaching losses may be slight even where much of the L, F, H layer has been reduced. Serious long term nutrient losses following burning are unlikely in ecosystem associations such as SBSd/09 (Spruce-horsetail ecosystem association) and SBSe/07, /08 (Oakfern and Devil's club ecosystem associations) both because sufficient vegetation is present soon after the fire to take up mobile elements, and incorporated organic matter in the soil profile provides sufficient exchange capacity to trap released nutrients. Prescribed fire which does much more than singe the litter layer should be avoided on mesic or drier sites. Even on moister sites with very coarse textured parent materials fire should be of low severity to minimize long term nutrient losses despite the attractiveness of short term increases in availability.

Moisture Holding Capacity, Infiltration and Water Repellency

The moisture holding capacity of coarse textured soils is largely dependent on surface organic matter. Therefore reduction in surface organic matter by fire would reduce the productivity of coarse textured soils not well supplied by seepage water. Burning, unless light, should therefore be avoided in xeric to submesic soils with coarse textures or with very fine texture (eg. Vanderhoof clay) as noted previously. Also as noted previously, infiltration rates may be reduced when all organic matter has been burned off because pores in mineral soil can become clogged by displaced mineral particles. Water repellency caused by condensation of volatilized organic substances has been noted in some coarse textured soils when burning has been moderate to severe.

pH

The presence of ash following burning raises the pH of soils. This could have adverse effects in soils developed on Limestone because forest productivity may in part be dependent on effects of organic matter reducing pH to favourable levels for conifers and associated micro-organisms. pH levels could become excessive on burned, dry Ponderosa pine sites, although the amount of material available for burning is probably insufficient to produce long term adverse effects even though the ph is raised. Beneficial or adverse effects of lasting significance caused by increased pH following burning do not seem to have been demonstrated.

Soil Microorganisms

Activity of soil microorganisms such as bacteria will be increased because burning increases temperature and pH of soils that were previously cool and acid. When soils are moist and adequately supplied with nutrients, increased microorganism activity may result in increased fertility and seedling growth. Exposed surface horizons may however become drier than they would have been with less insolation and exposure to wind. Microorganism activity may consequently be reduced in dry, shallow surface organic matter exposed by fire. Mycorrhizal organisms may also be reduced by extremely severe burning and reduction of organic matter. Effects on microorganisms are probably contributary causes, accentuating the undesirability of severe burning and organic matter reduction, rather than the main cause of reduced productivity.

Climate

The full range of choice in obtaining prescribed fires of different severities can be limited by climate. In wet climates, dry periods may not be long or frequent enough for fuels to dry sufficiently to produce severe burning even where desirable. Conversely, in dry climates a greater degree of

choice is possible. Even then, severe burning on wet sites, sites where severe burning could be potentially advantageous, may only be possible in drier parts of climatic cycles.

## VEGETATION

Prescribed fire can affect both the tree component of forests and the lesser, perhaps competing, vegetation. These effects can have an impact on forest productivity.

### Trees

When prescribed fire destroys the seed source available in lodgepole pine cones on slash or on the ground, fire will have affected the productivity of the site. This effect can be remedied by planting. But when budgetary constraints limit the planting option, ill advised fire destroying cones can be considered to have reduced forest productivity. Likewise, if advance regeneration of subalpine fir would have produced an acceptable new tree crop, prescribed fire to achieve some other objective would affect productivity unless the dollars are available for planting. Admittedly these are institutional rather than biological constraints on productivity, but they may be real nevertheless.

### Lesser Vegetation

Lesser vegetation can have an important direct negative effect on forest productivity by smothering seedlings. Sites then may become unproductive by lack of regeneration. Fire of sufficient severity can control the competitive effects of lesser vegetation without accompanying adverse effects when sites have sufficient incorporated organic matter and are sufficiently well supplied with moisture (eg. SBSe/08 Devil's club ecosystem association). Removal of

the shading effect of dense lesser vegetation can increase productivity through enhanced soil temperature promoting faster decomposition of surface organic matter and release of nutrients. Striking increases in productivity have been found with vegetation removal without direct modification of surface organic matter (McMinn 1982). These effects will be greatest where vegetation is dense (eg. SBSe/06 Moist thimble-berry - forb ecosystem association). Whether fire should be used for vegetation control depends on whether other parts of the ecosystem would be adversely affected - as they could be in moist thimble-berry - forb ecosystem associations on colluvial sites with limited organic matter accumulations.

Lesser vegetation can be extremely important after fire because uptake and cycling by plants retains nutrients made mobile by burning organic matter within the ecosystem. Such nutrients might otherwise be leached out and "wasted". The role of lesser vegetation in nutrient trapping is most important on sites with coarse-textured soils where nutrient retention by the exchange complex in the absence of organic matter is least effective. Fortunately light burning on such sites (eg. SBSe/01 Mesic Bunchberry-moss ecosystem associations), if burning is needed at all, would have low impact on vegetation regrowth. Vegetation regrowth therefore would have a role in nutrient retention. Fortunately in most ecosystems where severe burning is needed to control vegetation, adverse impacts would be least and conversely where vegetation has an important role in nutrient retention, the need for severe burning is likely to be low.

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# THE EFFECTS OF PRESCRIBED FIRE ON FOREST PRODUCTIVITY & WILDLIFE IN THE BOREAL AND SPRUCE-WILLOW-BIRCH ZONES OF PRINCE RUPERT FOREST REGION

T. Lewis[1]

## INTRODUCTION

To date, the available experience with prescribed fire in the northern areas of the Prince Rupert Region is meagre. Burning for silvicultural purposes is unknown; burning for wildlife habitat enhancement has been undertaken and the demand for it appears to be growing significantly.

The effects reported herein are based on observational experience gained during extensive reconnaissance throughout the Cassiar, Fort Nelson and Mackenzie T.S.A.'s as part of the Northern Fire Ecology project.

## BIOGEOCLIMATIC ZONES

Since the use and impacts of prescribed fire differ considerably between the Boreal White and Black Spruce (BWBS) and the Spruce-Willow-Birch zones, a review of these two zones is appropriate at this point -

Review of BWBS and SWB characteristics using slides

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## APPROACH

Impacts of either wildfire or prescribed fire on soil and site are determined by burning conditions (fire behaviour) and resulting depth of burn, and by fire frequency.

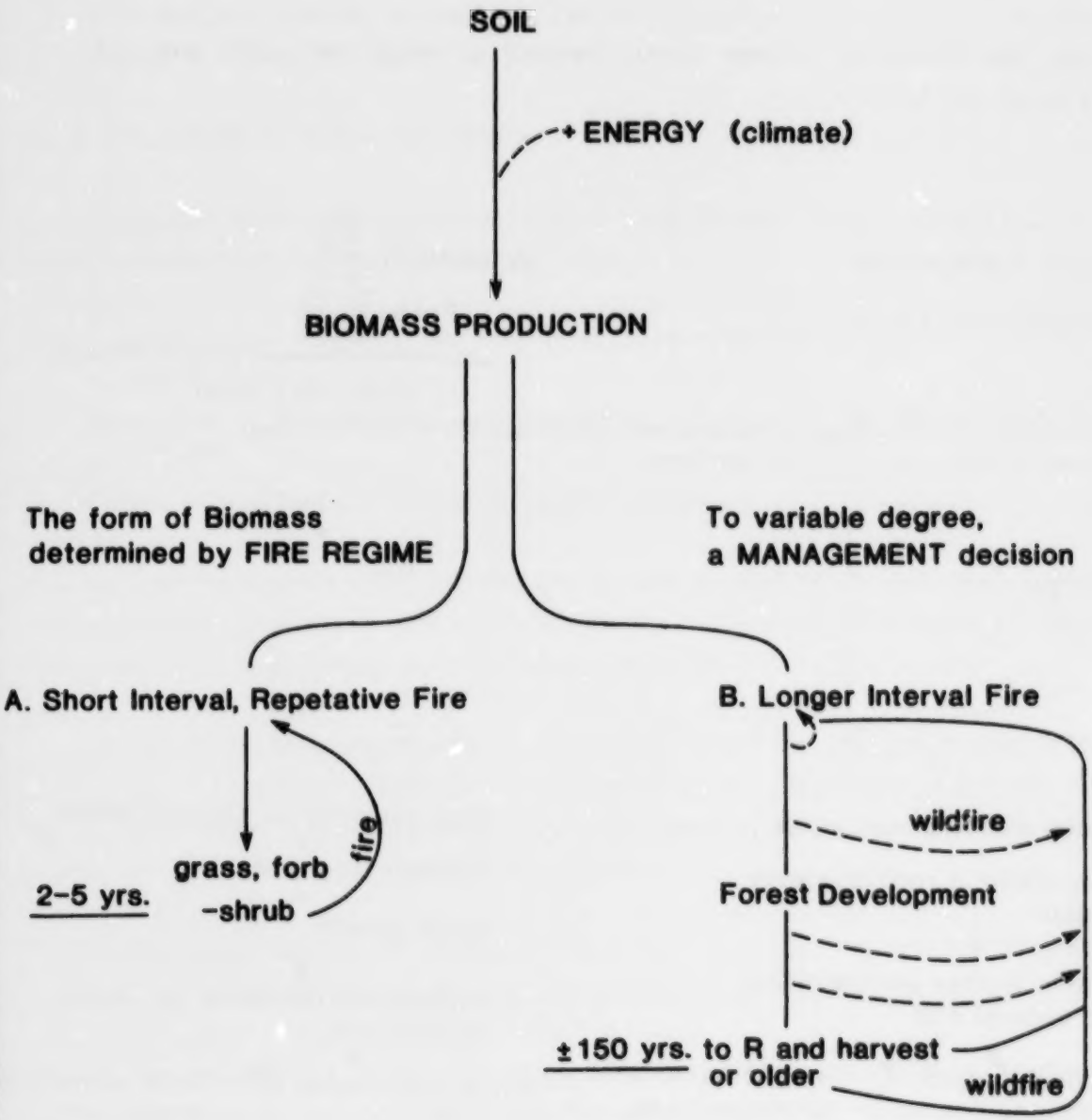
### A. Burning Conditions and Depth of Burn

Most forested northern ecosystems tend to accumulate considerable depths of partly decomposed organic layers on the mineral soil surface. This is particularly so in the Boreal zone under white spruce and black spruce - feathermoss types. Under the more open white spruce forests of the Spruce-Willow-Birch, these organic accumulations are somewhat less. As a result, perhaps the best way of assessing the relative impact of fire is an assessment of the depth of burn or degree of consumption of these organic layers. Due regard must be given to the spatial distribution of burn depth, which is highly variable. (see Hawkes).

Although we received a number of reports of "intense" fires that burned "down to mineral soil" over "significant" areas of wildfires, we were rarely able to find such effects. They appear to be restricted to particularly well drained sites such as gravelly glacial outwash terraces and coarse colluvial soils of steep, south to west aspects. These xeric sites are atypical of the zone in that they have only thin surface organic layers. Such sites support a succession of lodgepole pine communities in a similar fashion to similar sites in central and southern Interior B.C.

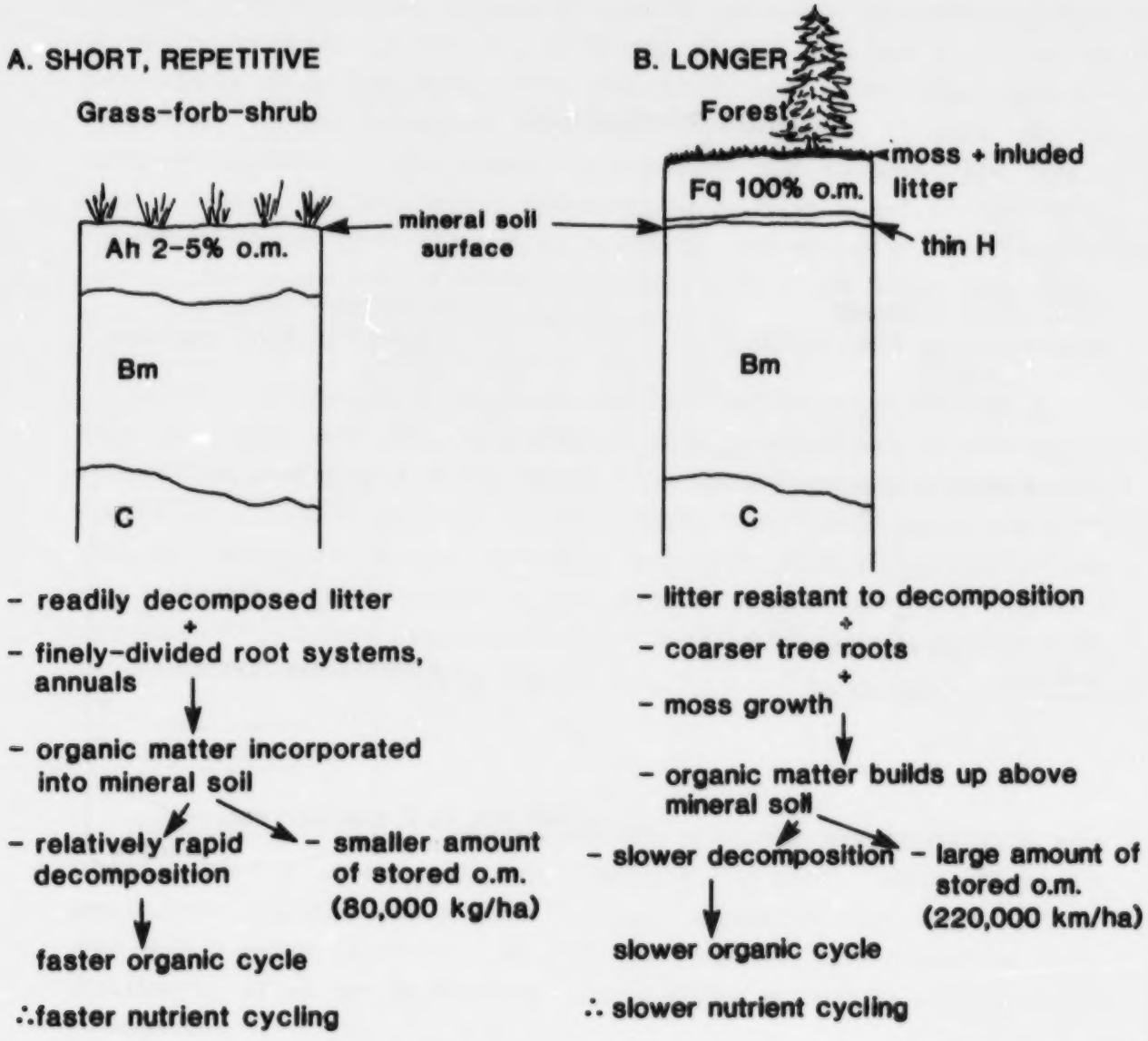
### B. Fire Frequency

The effects of fire frequency on the ecosystem are potentially more powerful than the burning conditions of any one fire event. These effects are particularly dramatic when a short interval, repetative fire regime exists. When such a regime is natural, we think in terms of "fire climax" or "fire disclimax". If we are to prescribe such a regime we need to understand its consequences.


SOIL
+ ENERGY (climate)
BIOMASS PRODUCTION
The form of Biomass determined by FIRE REGIME
To variable degree, a MANAGEMENT decision
A. Short Interval, Repetative Fire
grass, forb -shrub
fire
2-5 yrs.
B. Longer Interval Fire
wildfire
Forest Development
±150 yrs. to R and harvest or older
wildfire

WHAT ARE THE EFFECTS OF DIFFERENT FIRE REGIMES ON THE SOIL AND THE ORGANIC CYCLE?

Consider the following extreme cases, keeping in mind that both are not realistic on all sites -



Consideration of these two rather extreme cases raises a number of questions -

Is A "better" than B? B "better" than A?
Is A or B inherently "good" or "bad"?

In short, how do we judge."goodness"?

If we can agree that the ability of a site to maintain its potential for biomass production is the key concern,

THEN, before we can assess A and B we need to consider the extent of

1. nutrient losses (soluble)
2. erosion of soil and included nutrients.

1. Losses of nutrients in solution (leaching losses)

We have no experimental information to assess whether or not such losses are occuring. However, a number of applicable factors and observations favour the view that these losses are not large, including -

a) the relatively low rainfall climate and resulting lack of through-flow in the soils. This is indicated in soil profiles developed in calcareaous parent materials by the presence of Cca horizons within a metre of the soil surface.

b) the preponderance of medium to fine textured soil materials (adequate CEC) derived from sedimentary, metamorphic and volcanic rocks.

c) the ability of available secondary vegetation to quickly colonize burned over areas in spite of the adverse regional climate. In other areas this has been shown to be a key mechanism in retaining nutrients on-site after the occurence of fire.

2. Losses of soil and nutrient by accelerated erosion.

The presence of these losses can be detected quite well by extensive observational experience gained in the Northern Fire Project. Anticipated losses included erosion by both overland flow and mass movement. Overland flow occurs when rainfall intensity or snowmelt rate exceeds the infiltration rate of the soil and is evidenced by sheet erosion, rill and gully development. Mass movement losses that implicate fire might include the smaller scale events such as debris slides, debris avalanches, debris torrents, and small slump-earthflows but exclude large-scale landslides, rockfalls and large slump-earthflows.

Perhaps surprisingly, our extensive work revealed that acceleration of erosion by wildfires is rare. In the Boreal zone undoubtedly the widespread occurrence of thick surface organic layers (hemimors) provides excellent protection for the underlying mineral soil and materials. Their effectiveness is increased by the "patchy smouldering" type of fire behavior. Where organic layers are thin in the Boreal, as on xeric sites, the underlying materials are coarse textured, highly permeable and hence resistant to erosion (eg. gravelly or sandy glaciofluvial materials).

Even in the Spruce-Willow-Birch zone, where surface organic layers tend to be thinner, the depth of burn is shallow and/or discontinuous enough to leave adequate protection to the mineral soil on the majority of sites. Notable exception in the SWB include similar coarse textured glaciofluvial materials to those of the BWBS and coarse textured, rubbly colluvial materials. Both are coarse, permeable and resist erosion by running water. Furthermore climate is not wet enough to predispose such slopes to debris slide or avalanche type mass movements. Sufficient excess soil water to develop the necessary positive pore-water pressures to trigger such rapid mass movements can build up on steep, north-aspect slopes that experience either permafrost or high ice-content seasonal frost. In these ecosystems fire can drastically alter the heat balance by destroying surface insulating layers of moss and organic matter. This leads to a deepening of the zone of seasonal melting

("active Layer") and supersaturation above the frozen material below. Debris slides and debris avalanches may result, as they did after the 1981 fire in Kwadacha Park. Note that this was the only example of dramatic erosion resulting from fire that we observed. However, such ecosystems with adverse rather than favourable microclimates would not be candidates for prescribed fire. These observations lead to the belief

THAT, A, with the exception of a limited number of special situations, is inherently no better nor worse than B since we have changed the form of the biomass production and the dynamics of organic and nutrient cycling but not the potential for biomass production.

In large part, then, "good" or "bad" is determined by management objectives.

As an aid to considering various management options and protection priorities, the following approach is suggested. Many refinements can be incorporated using the existing experience of managers and as research fills in gaps.

| MANAGEMENT OPTIONS | ZONE: | S W B | B W B S |
|---|---|---|---|
| Longer term fire | Benefits | - 1-1.5 $m^3$/ha yr. | Benefits - 4-5 $m^3$/ha yr. |
| | Costs | - reduced browse<br>- caribou, sheep elk (30 Tuchodi) | Costs - reduced upland browse<br>- moose ? |
| Short-term Repetitive Fire | Benefits | - increase browse<br>- caribou, sheep<br>- elk (300 Tuchodi) | Benefits - increase upland browse<br>- moose ? |
| etc | Costs | - 1-1.5 $m^3$/ha yr. | Costs - 4-5 $m^3$/ha yr. |
| expand | | Refine by examined specific ecosystem association or ecosystem mosaics within these zones. | |

# IMPACTS OF PRESCRIBED FIRE (SLASHBURNING) ON FOREST PRODUCTIVITY, SOIL EROSION, AND WATER QUALITY ON THE COAST

M.C. Feller[1]

## Introduction

This paper briefly reviews the published literature on the effects of slashburning on forest productivity, soil erosion, and water quality in coastal B.C. Much of it has been extracted from a broader review of the ecological effects of slashburning in B.C. (Feller 1982). Due to the scarcity of published work on the effects of shashburning in coastal B.C. on erosion and water quality in particular, it has been necessary to review studies conducted in other regions.

A notable feature of the literature on slashburning is that for any effect reported in one study, it is usually possible to find the opposite effect reported in another study. The most important factors controlling the effects of slashburning are those related to soils, climate, vegetation, fire behaviour and impact of the burn, and the slash characteristics. All these factors tend to interact wih one another resulting in complex situations from which relatively few generalizations are possible. It is this complexity which has led to the contradictory nature of the literature.

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## 1. Effects of slashburning on forest productivity

Forest productivity is a function of several factors. It depends to a large extent on which particular tree species is/are present and the ability of this/these species to grow under the prevailing ecological conditions. Obviously the prevailing ecological conditions are also important. Of these, microclimate and soil moisture and nutrient status are perhaps the most important. The activity of certain insects or disease organisms may be locally important at times.

Few studies have attempted to integrate all these factors. Consequently, in the following discussion, firstly the effects of slashburning on the growth and survival of the most important coastal tree species is considered. Then follows a brief discussion of the effects of slashburning on ecosystem characteristics which are important determinants of forest productivity. The tree species considered are: Abies amabilis, Abies grandis, Abies lasiocarpa, Chamaecyparis nootkatensis, Picea engelmannii, Picea sitchensis, Pseudotsuga menziesii, Thuja plicata, Tsuga heterophylla, and Tsuga mertensiana.

It is known that trees grow and behave in ways that depend on the ecosystems or sites in which they grow (eg. Daubenmire 1974, Krajina 1969). The response of a tree species to slashburning will logically vary according to the ecosystem or site in which that species is growing. Thus, by removing organic matter and living plants, and by exposing the soil surface, slashburning will usually convert a site to an early successional state. This will favour the establishment and growth of shade-intolerant early successional tree species and may have adverse effects on the establishment and growth of those species that are shade-requiring. Shade requirements partly depend on climate - in general the warmer the climate and drier the soil the more tolerant or requiring any given species is of shade (Daubenmire 1974, Krajina 1965, 1969). Consequently, a species may be shade-requiring in one ecosystem but not in another. It is more likely to be adversely affected by slashburning in the former ecosystem.

This site-specific response of trees to slashburning has generally not been adequately recognized in the slashburning literature and can account for much of the debate concerning the effects of slashburning on the regeneration and growth of any particular tree species. This debate can also be attributed partly to differences in fire intensity used in different studies and partly to the fact that some authors discuss natural regeneration whereas others discuss artificial regeneration by planting or direct seedling.

In the following discussion, the effects of slashburning on the major tree species of Coastal B.C. are reviewed by species. Whenever possible, these effects are discussed on a site-specific and biogeoclimatic zone basis. Krajina's (1976, 1978) biogeoclimatic zones of British Columbia provided generalized climatic integration of ecosystems, to which shade requirement and response of trees to slashburning were related. Although there have been some changes in B.C.'s biogeoclimatic zones, these changes have not been made readily available in published form. Consequently, the zones as given by Krajina (1969) are used.

Abies amabilis (Dougl.) Forbes[2] - amabilis fir

Ambilis fir is very shade-tolerant (Fowells 1965, Garman 1955, Krajina 1969, Minore 1972, Schmidt 1957) and is shade-requiring on drier sites (Krajina 1969). It has been reported to be adversely affected by slashburning (Garman 1955, MacBean 1941, Schmidt 1957), although Gockerell (1966) reported that amabilis fir seedling growth was better on burned than on unburned areas. Klinka and Pendl (B.C. Ministry of Forests, unpublished manuscript) concluded that the most detrimental effects of slashburning in high elevation ecosystems in the Vancouver Forest Region were the destruction of the existing advance regeneration of amabilis fir, mountain hemlock and western hemlock,

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[2]All scientific names are from V.J. Karjina (1969), Ecology of forest trees in British Columbia, Ecology of Western North America 2, Department of Botany, University of B.C., Vancouver, B.C., 146 p.

and the delaying of natural regeneration of these species on burned areas. Minore and Dubrasich (1981) reported that slashburning increased the time taken by amabilis fir to reach 60% stocking.

Abies grandis (Dougl.) Lindl. - grand fir

Grand fir is shade-tolerant (Fowells 1965, Krajina 1969) although it is shade-intolerant on the wetter sites on which it grows (Krajina 1969). There appears to be no published information on the effects of slashburning on coastal populations of grand fir. However, under interior conditions grand fir has regenerated on slashburned areas although it has been adversely affected by burning on exposed south-facing sites (Shearer 1976) and on sites where it requires shade (Wittinger et al. 1977). Haig et al. (1941) found that burning retarded germination of grand fir.

Abies lasiocarpa (Hook.) Nutt. - subalpine fir

Subalpine fir is a very shade-tolerant species (Fowells 1965, Karjina 1969) and is shade-requiring on the drier sites on which it grows (Krajina 1969). It has been generally adversely affected by slashburning (Endean and Johnstone 1974, Muri 1955, Smith 1955, Vogl and Ryder 1969). Smith (1960) reported that initial growth of subalpine fir seedlings was better on burned than on unburned seedbeds, but survival was poorer. Alexander (1966) reported subalpine fir stocking to be better on undisturbed forest floor than on disturbed seedbeds. Boyd and Deitschmann (1969) reported that slashburning resulted in poorer stocking of subalpine fir compared to untreated or scarified areas.

Chamaecyparis nootkatensis (D. Don) Spach - yellow-cedar

The shade tolerance of yellow-cedar is comparable to that of amabilis fir (Fowells 1965, Krajina 1969) although little appears to be known about its

requirement for shade. It is a desired timber species and would be preferred on the moister, richer sites where it grows best (Brooke et al. 1970). Little appears to be known about the effects of slashburning on yellow-cedar growth.

Picea engelmannii Parry - Engelmann spruce

Engelmann spruce is moderately shade-tolerant (Fowells 1965, Krajina 1969) and grows best on the richer sites (Krajina 1969). Clearcutting may not always be the most suitable cutting method for this species (Alexander 1974a, 1974b, Day 1970, Ronco and Noble 1971), but when clearcutting does occur slashburning has been considered to produce adverse conditions for Engelmann spruce (Alexander 1977, Vogl and Ryder 1969). However, Engelmann spruce can grow on slashburned areas where it can often find shaded mineral soil seedbeds which it prefers (Dobbs 1972, Roe et al. 1970, Shearer 1980, Smith 1955). Boyd and Deitshcmann (1969) reported that slashburning in northern Idaho improved stocking from natural regeneration compared to that from untreated or lightly scarified areas. However, the best stocking occurred on moderately or heavily scarified areas.

Roe et al. (1971) considered Engelmann spruce not to be favoured by fire in situations where it was a climax species. Intense slashburns which exposed mineral soil might favour growth of Engelmann spruce, but such slashburns have presented fire control problems (Endean and Johnstone 1974, Smith 1955).

Picea sitchensis (Bong.) Carr. - Sitka spruce

Sitka spruce is relatively shade-intolerant, being generally less tolerant than the major species - western hemlock and western redcedar - with which it grows (Fowells 1965, Krajina 1969). It has been generally found to be favoured by slashburning (Embry 1963, Harris 1966, Krajina 1969, Phelps 1973, Ruth 1974), although Gockerell (1966) found that Sitka spruce seedling growth was better on unburned than on burned areas. Slashburning has favoured Sitka spruce over western hemlock (Embry 1963, Harris 1966).

Pseudotsuga menziesii (Mirb.) Franco - Douglas-fir

Douglas-fir is generally intermediate in shade-tolerance (Fowells 1965, Krajina 1969) but it can be shade-requiring, shade-tolerant and shade-intolerant depending on climate and soil moisture regime (Krajina 1969). The effect of slashburning on both coastal and interior varieties of Douglas-fir has been the object of considerable debate.

In the case of the coastal variety, one group of workers reported that slashburning was beneficial for Douglas-fir regeneration or growth, generally claiming that, while regeneration may be retarded on severely burned ground, it was enhanced on the lightly burned ground which consituted over 90% of most slash burns (Bever 1954, Miller et al. 1974, Morris 1970, Steen 1966, Tarrant 1956, Tarrant and Wright 1955, Worthington 1953). Other workers reported that slashburning retarded regeneration mainly due to increased soil temperature and increased evaporation of water to the soil, causing drought and heat stresses (Baker 1968, Baker and Phelps 1969, Isaac 1938, Jablanczy 1964, Knight 1964, Lavender et al. 1956, Munger and Mathews 1941, Neal et al. 1965). Several workers considered slashburning to be more harmful on the drier and poorer sites (Baker 1968, Isaac 1938, 1963, Jablanczy 1964, McCulloch 1944, Mueller-Dombois 1960). Gockerell (1966) reported that the survival of planted trees was greater on burned than on unburned areas. However, height growth of planted seedlings was greater on unburned areas and animal damage was greater on burned areas.

It has been accepted that Douglas-fir germinates best on mineral soil (Fowells 1965, Isaac 1938, Miller et al. 1974) but Mueller-Dombois (1960) considered that unburnt organic materials did not normally provide an inferior seedbed. In slashburned areas Douglas-fir establishment was more successful on mineral soil than on burned organic materials because of the greatly reduced moisture holding capacity of charred organic materials which caused the mineral soil to be more favourable for seedling establishment and survival. Minore (1972) found that in the presence of shade, a forest floor seedbed benefited the early growth of Douglas-fir.

In the drier Coastal Western Hemlock biogeoclimatic subzones where Douglas-fir is less shade-tolerant than any of its major competitors on the mesic and wetter sites, slashburning has favoured it over its competitors on these sites (Allen 1954, Bunce 1960, Gockerell 1966, Jablanczy 1964, Weaver 1974). Its competitors have usually regenerated naturally somewhat later (Mueller-Dombois 1960, Osborn 1968, Weaver 1974). Thus, slashburning is likely to favour growth of Douglas-fir on the mesic and wetter sites. However, in the wetter Coastal Western Hemlock biogeoclimatic subzones climatic conditions may not be optimum for Douglas-fir and other more productive species (which are adversely affected by slashburning) might be desired.

Thuja plicata Donn. ex D. Don in Lamb. - western redcedar

Western redcedar is very shade-tolerant (Fowells 1965, Krajina 1969) and requires shade to establish on the driest sites on which it grows. In the Interior Douglas-fir biogeoclimatic zone it requires such shade even on the intermediate and moderately moist sites (Krajina 1969).

Western redcedar can regenerate on burned seedbeds (Haig et al. 1941, Jablanczy 1964, Schmidt 1955). However, Soos and Walters (1963) found that western redcedar seedling mortality was greater on burned than on unburned mineral soil. Jablanczy (1964) found that simulated slashburning in the laboratory had variable effects on western redcedar growth depending on burn intensity, site type, and age of seedling. Haig et al. (1941) reported that western redcedar was particularly susceptible to drought and stem girdling caused by high soil surface temperatures.

Tsuga heterophylla (Raf.) Sarg. - western hemlock

Western hemlock is generally a very shade-tolerant species (Fowells 1965, Krajina 1969), although towards the northern end of its range in Alaska it

becomes less shade-tolerant and may not be disadvantaged by increased exposure to light (Andersen 1956). Western hemlock requires shade to establish on the drier sites in which it grows in the Coastal Western Hemlock and Interior Western Hemlock biogeoclimatic zones. It requires such shade for all sites in the Coastal Douglas-fir biogeoclimatic zone (Krajina 1969).

With respect to coastal populations of western hemlock, although there are some reports of slashburning aiding regeneration (Allen 1944, Berntsen 1955, Hetherington 1965, Mansell 1961) most work indicates that slashburning is generally detrimental to the regeneration and initial growth of this species. The adverse effects include direct killing of advance regeneration or causing mortality of young seedlings by drought or frost heaving (Bunce 1960, Gockerell 1966, Harris 1966, MacBean 1941, Roe et al. 1971, Ruth 1974, 1976, Soos and Walters 1963). Western hemlock seedlings are particularly susceptible to drought (Haig et al. 1941, Krajina 1969) and generally prefer some shade (Fowells 1965, Harmon 1963, Polk and Boe 1951, Ruth 1974, Soos and Walters 1963). Both these factors are influenced by slashburning, usually to the detriment of the seedlings. Jablanczy (1964) found that simulated slashburning in the laboratory had variable effects on hemlock growth depending on fire intensity, site type, and age of seedling.

In general, burning in western hemlock forests favours the less shade-tolerant Douglas-fir over western hemlock (Ruth 1974, 1976, Weaver 1974).

Tsuga mertensiana (Bong.) Carr. - mountain hemlock

Mountain hemlock is a very shade-tolerant species (Fowells 1965, Krajina 1969), but it does not require shade for establishment (Krajina 1969). Boyd and Deitschmann (1969) found in northern Idaho that burning slash produced better stocking of natural regeneration compared to leaving slash untreated. However, scarification generally produced better stocking than did burning. Minore and Dubrasich (1981) reported that slashburning in Oregon increased the time taken by mountain hemlock to reach 60% stocking. Apart from these

reports no other publications could be found on the effects of slashburning on mountain hemlock.

The available literature on the effects of slashburning on the species discussed above was used together with the reported shade requirements of the species (Krajina 1969) to prepare a summary of the general impact of slashburning on these species (Table 1). The table includes predicted effects on germination, initial growth, and survival of naturally regenerated seedlings, as well as the initial growth and survival of artificially planted seedlings on either broadcast slashburned or spot burned areas. The long-term effects of slashburning on tree productivity have yet to be documented.

The above discussion has been concerned mainly with short-term productivity. Long term productivity also depends on the particular tree species under consideration and its adaptation to ecosystem conditions, but it also depends, perhaps to a greater extent, on sustained or cumulative changes imposed on the soil by slashburning. The most important of these changes are probably 1) loss of surface soil by erosion (to be discussed in the report), 2) loss of nutrients and changes in ecosystem nutrient status, and 3) changes in soil biology.

Effects of slashburning on ecosystem nutrient status

Fire releases nutrients within slash and forest floor materials both to the atmosphere by volatilization, and to the mineral soil via leaching of ash. This results in:

(a) a temporary increase in soil pH and in "available" nutrients in the mineral soil (eg. Feller 1982).

(b) usually a loss of nutrients from the site via leaching and via overland flow on steep slopes (eg. Feller 1982).

TABLE 1. Summary of the likely regeneration and early growth response to slashburning of the major tree species in coastal British Columbia according to biogeoclimatic zones and sites[1].

| Tree Species | Biogeoclimatic zone | Response to slashburning |
|---|---|---|
| *Abies amabilis* | Coastal Western Hemlock)<br>Mountain Hemlock ) | adverse on intermediate to dry sites, beneficial on others |
| *Abies grandis* | Coastal Douglas-fir )<br>Coastal Western Hemlock) | insufficient information available |
| *Abies lasiocarpa* | Engelmann Spruce - )<br>Subalpine Fir ) | adverse on intermediate to dry sites, beneficial on others |
| *Chamaecyparis nootkatensis* | Coastal Western Hemlock)<br>Mountain Hemlock ) | insufficient information available |
| *Picea engelmannii* | Engelmann Spruce - )<br>Subalpine Fir ) | variable effects depending on site factors and degree of forest floor removal |
| *Picea sitchensis* | Coastal Western Hemlock) | generally beneficial |
| *Pseudotsuga menziesii* | Coastal Douglas-fir ) | adverse on the drier and poorer sites, beneficial on others except for severe burns |
| | Coastal Western Hemlock) | adverse on the driest sites, beneficial on others except for severe burns |
| *Thuja plicata* | Coastal Douglas-fir )<br>Coastal Western Hemlock) | adverse on the drier sites, beneficial on others |
| *Tsuga heterophylla* | Coastal Douglas-fir )<br>Coastal Western Hemlock) | generally adverse |
| *Tsuga mertensiana* | Mountain Hemlock )<br>Engelmann Spruce - )<br>Subalpine Fir ) | insufficient information available |

[1]Sites as used throughout this table refers only to those in which the species grows (Krajina 1969).

Subsequent wind erosion may remove more ash particles and more nutrients (DeByle 1976, Lewis 1974, Wells et al. 1979) although some of these air-borne nutrients may be returned to the ground in adjacent areas by precipitation (Clayton 1976, Lewis 1974).

The literature suggests that nutrient losses via leaching are very slight in relation to losses via volatilization and fly-ash (Feller and Kimmins 1982, Grier 1972, 1975) (see also Table 2).

Volatilization and fly-ash losses appear to be controlled mainly by the intensity of the fire and the quantity of organic matter burned (Table 3) (Kimmins et al. 1982, Knight 1966, Tiedemann and Anderson 1980). Fires have often caused relatively large losses of the volatile nutrient-nitrogen (Debell and Ralston 1970, Grier 1975, Isaac and Hopkins 1937, Knight 1966) but substantial losses of other nutrients have also been reported (Grier 1975, Isaac and Hopkins 1937, Kimmins et al. 1982, Tiedemann and Anderson 1980).

There is considerable debate in the literature as to whether or not these losses are significant in view of the fact that a) the quantity of "available" nutrients in the soil is usually increased by burning (Ahlgren and Ahlgren 1960, Wells et al. 1979) and, b) the effects of burning on the levels of available nutrients may not be apparent for some time after the burning (Kraemer and Hermann 1979, Mroz et al. 1980).

The increase in the quantity of available N in the soil following burning may be partly due to enhanced nitrification and nitrogen fixation, as well as leaching of mineralized N into the soil, since increased soil temperatures and pH values would favour the growth of nitrifying and free-living nitrogen fixing bacteria (Ahlgren and Ahlgren 1960, Jurgensen et al. 1981, Mroz et al. 1980, Wollum and Davey 1975). Mroz et al. (1980) reported only very brief (5 weeks) increases in available soil N following low intensity burns of different forest floors in the laboratory. They considered these temporary increases to be of little value for subsequent regeneration because some of

TABLE 2. Estimated nitrogen budgets in a clearcut and a clearcut and slashburned western hemlock - western redcedar watershed in southwestern B.C.

| | | kg/ha Clearcut | Clearcut + slashburn |
|---|---|---|---|
| OUTPUTS | | | |
| | Stream (solution) | 170 | 90 |
| | Stream (particles) | 80 | 80 |
| | Logs | | 230 |
| 310 | | | |
| | Atmosphere (burn) | 0 | 980 |
| | Denitrification | ? | ? |
| Total output | | 480+ | 1460+ |
| INPUTS | | | |
| | Precipitation | 320 | 320 |
| | Dry fallout | ? | ? |
| | Weathering | 6 | 6 |
| | N fixation (red alder) | 2900 | 400 |
| | N fixation (non-symbiotic) | ? | ? |
| Total input | | 3226+ | 726+ |

Source: Unpublished data of M.C. Feller.

TABLE 3. Nutrient losses to the atmosphere following slash fires in western hemlock - western redcedar ecosystems in southwestern B.C.

| Year | Total energy released ($KJ/m^2$) | Average rate of spread (m/min) | N | P | K | Ca | Mg |
|---|---|---|---|---|---|---|---|
| | | | (kg/ha) | | | | |
| 1974 | 275,600 | 0.6 | 982 | 16 | 37 | 154 | 29 |
| 1981 | 217,800 | 0.2 | 488 | 9 | 17 | 87 | 7 |

Source: Unpublished data of M.C. Feller.

the increased $NO_3$ could be lost by leaching. Jurgensen et al. (1980) reported increases in available N in western redcedar - western hemlock forest soils in Idaho and lodgepole pine forest soils in Wyoming following slashburning, but the burning caused decreases in N fixation rates in the soil. As can be seen from the discussion, slashburning can have either adverse or beneficial effects on the various processes controlling soil available N levels.

Soils in ecosystems with relatively low organic matter decomposition rates, such as those of the more northerly boreal spruce and perhaps some northern coastal forests, commonly have thick forest floors which contain a high proportion of the total site nutrient capital and which may supply trees with a major portion of their nitrogen (Krause et al. 1978, Zasada et al. 1977). Harvesting of wood biomass and destruction of these forest floors by clearcutting and slashburning could have a significant impact on site fertility.

A study of the available literature in Kimmins et al. (1982) indicates that light to moderate intensity and impact slashburns in western North American coniferous forest can remove up to 50% of the total N present in the forest floor. Kimmins et al. (1982) also found that the quantity of N, P, K, Mg, and Ca lost from burning the forest floor of western hemlock - western redcedar forests in the Drier Maritime Coastal Western Hemlock biogeoclimatic subzone of B.C. was closely related to both the depth and the quantity of forest floor burned.

There have been very few studies of the significance of slashburning - induced nutrient losses in a long-term dynamic context. In the study discussed by Kimmins et al. (1982), Feller and Kimmins (1982) found that N, Mg, and Ca losses resulting from clearcutting could be replaced by precipitation alone over an 80 year rotation, but not P and K losses. However, when a low to moderate intensity slashburn followed this clearcutting, precipitation inputs over an 80 year period were insufficient to replace any of the measured nutrient losses, except for Mg. Over much of the

burnt area the N losses following clearcutting and slashburning were unlikely to be replaced by the sum of the N inputs from precipitation, mineral weathering, and biological fixation by the red alder present, over the subsequent 80 years, suggesting a significant depletion of the site's N reserves. The N data are given in Table 2.

In view of the close association between organic material loss and nutrient loss, the significance of slashburning-caused nutrient losses would depend on the nutrient content of the forest floor relative to that of the mineral soil, and the amount of forest floor burned, as well as the forest's nutrient requirements.

The organic matter content of the soil is strongly related to soil fertility since it commonly accounts for more than half the CEC of a soil and most of the soil nitrogen, is primarily responsible for aggregate stability, and is the major source of energy for the decomposer microorganisms. Burning will destroy some of this organic matter, the extent of the destruction depending mainly on the fire itensity, the extent to which the organic matter is incorporated into the soil, and the pre-burn moisture content of the soil (Ahlgren and Ahlgren 1960, Austin and Baisinger 1955, Baker 1968, Dyrness and Youngberg 1957, Grier 1972, Kraemer and Hermann 1979, Lutz 1956, Wells et al. 1979, Youngberg 1953). The effects are usually limited to the uppermost soil layers and recovery times have ranged from one to over 50 years. Reductions of organic matter are thus greatest on the poorer sites where the organic matter is not incorporated into the soil but accumulates on the mineral soil surface (mor humus forms) or where there is a layer of organic material over bedrock or parent material (terrestrial organic soils with mor humus forms) (Wells et al. 1979).

Harvey and co-workers in the U.S. Rocky Mountains (Harvey et al. 1980a, 1980b, Jurgensen et al. 1980) have stressed the importance of woody materials in soils. They considered that maintenance of these materials is particularly important in harsh or marginal sites. Potentially, the most adverse effects on site productivity of burning-induced losses of woody materials would occur on these harsh or marginal sites.

## EFFECTS OF SLASHBURNING ON SOIL BIOLOGY

### Microorganisms and Disease Organisms

Slashburning-induced changes in soil temperatures, moisture relations, pH, and nutrient status may cause changes in the numbers and species composition of soil microorganism communities.

Burning has been found to cause either increases, decreases, or no effect on microorganism populations, depending on fire intensity, degree of destruction of organic matter, soil temperature regimes, soil moisture following burning, and occurrence of rain after burning (Ahlgren and Ahlgren 1960, Bissett and Parkinson 1980, Bollen 1974, Harvey et al. 1976, Knight 1964, Neal et al. 1965, Wells et al. 1979, Wright and Tarrant 1957, 1958). Microorganisms are more susceptible to heat from burning when soils are moist (Wells et al. 1979), but rain immediately after burning can assist the recovery of any depleted microorganism populations (Harvey et al. 1976).

#### (a) Effects on beneficial microorganisms

Burning usually causes a temporary decrease in mycorrhizae on conifers although regeneration of these conifers is apparently unaffected (Harvey et al. 1976, 1980b, Mikola et al. 1964, Tarrant 1956, Wright and Tarrant 1958). Nitrifying bacteria are particularly sensitive to soil heating and can be reduced by burning although their populations apparently recover rapidly. Increased nitrate levels in soils soon after burning have been attributed to increases in nitrifying fungi (DeBano et al. 1979). Such increases in nitrate can also result from increases in nitrogen fixing bacteria (Ahlgren and Ahlgren 1960, Bollen 1974, Harvey et al. 1976), although Jurgensen et al. (1980) reported that slashburning decreased nitrogen fixing bacteria in western hemlock forests in Idaho and lodgepole pine forests in Wyoming.

(b) Effects on detrimental microorganisms and disease organisms

Slashburning can suppress many types of pathogenic microorganisms by removing their substrate (slash) (Algren and Algren 1960, Boyce 1961, Fellin 1980, Harvey et al. 1976, Nelson and Harvey 1974, Wells et al. 1979). Slashburning has also been used to destroy the slash of trees infected with dwarf mistletoes in order to reduce the infection of new seedlings (Alexander and Hawksworth 1975, Fellin 1980, Gockerell 1966, Shea 1966, Smith and Baranyay 1970). Slashburning may increase feeder root diseases of young conifers, and of Rhizina undulata in particular (Ahlgren 1974, Harvey et al. 1976, Morgan and Driver 1972, Nelson and Harvey 1974, Tarrant 1956, Wright and Bollen 1961). Rhizina is favoured by fire because germination of its spores is enhanced by heat and mycelial growth is stimulated by the addition of heated extract of conifer roots to the medium (Ahlgren 1974, Harvey et al. 1976).

Boyce (1961) considered that burning is the best method of slash disposal to reduce the incidence of wood-destroying fungi provided that all pieces of wood and stumps are charred; fungi attacking living trees rarely develop on charred wood. However, he concluded that because the destruction or charring of large pieces of slash requires such a severe fire it is unlikely that the infection of living trees by fungi developing on the unburned slash would be serious enough to justify the detrimental effects of the burn on the soil.

Soil Fauna

Soil fauna include earthworms, insects, spiders, centipedes, millipedes, etc. These organisms may spend only a portion of their lives in the forest floor or mineral soil, the remainder being spent on the above-ground vegetation. Many of these organisms are important in maintaining high soil permeability and in returning nutrients to the soil through decomposition of litter.

The impact of slashburning on soil fauna depends on fire intensity, the degree of organic matter loss, the degree of exposure of the soil surface, and the type of organisms present.

Slashburning may retard insect attacks on trees or seedlings by removing habitats favourable to growth of insects. For example, plantation weevil larvae breed in stumps and slash, as do bark beetles. Burning of the slash may remove potential breeding grounds (Ahlgren 1974, Ahlgren and Ahlgren 1960, Fellin 1980, Mitchell and Martin 1980, Mitchell and Sartwell 1974). Graham (1922) considered that the removal of only the smaller and more flammable portions of the slash by a slash fire has little or no deterrent influence upon many insect pests because most of the potentially injurious species are found only in the larger logs, branches and stumps.

Burning has often been shown to cause a reduction in soil fauna, particularly earthworms and spiders, but not so much for ants (eg. Feller 1982). In Finland these reductions have been found to persist for up to 27 years (Karppinen 1956). The population reductions have been attributed partly to the direct heat of the fire and partly to the altered soil environment - greater temperature fluctuations, a drier soil surface, and reduced organic matter.

Slashburning has increased damage to conifer seedlings in coastal B.C. by the weevil Steremnius carinatus by removing the vegetation and plant materials the weevil usually eats, forcing the weevil onto newly planted seedlings (Condrashoff 1969).

In their discussion of slashburning in the U.S. Pacific Northwest Mitchell and Sartwell (1974) concluded. "In most cases the best entomological practice appears to be to preserve beneficial insects whenever possible. Generally that would mean leaving slash untreated. It may also mean changing harvest methods from clearcutting to selection or shelter-wood cutting to maintain moisture and reduce heat where populations live on the forest floor".

## 2. Effects of slashburning on soil erosion

### (a) Surface erosion

Burning can increase overland flow and surface soil eriosion due to

1. removal of protective vegetative cover and forest floor materials,
2. reduction in soil porosity,
3. formation of a hydrophobic layer in the soil,
4. breakdown in soil structure, or
5. concentration of runoff by increasing the amount of exposed bedrock.

(eg. Feller 1982).

The likelihood and severity of erosion in a slashburned soil depends mainly on

(a) climate
(b) the intrinsic erodibility of the soil
(c) the rate of revegetation, and
(d) the degree of removal of the forest floor,
(e) the intensity of the fire

(Dyrness 1967, Farmer and van Haveren 1971, Megahan 1978, Rice et al. 1972).

#### (a) Climate

Of the climate characteristics, precipitation intensity and timing are the most important, although wind can also be important in steep mountainous terrain (Megahan 1978). Heavy rain shortly after burning, and before a protective layer of vegetation has become established, has the greatest potential for causing severe erosion. Erosion from fire-induced water repellent (hydrophobic) soils is more serious in drier climates (DeBano and Rice 1971, Dyrness 1976).

(b) Soil erodibility

The intrinsic erodibility of the soil depends mainly on soil aggregate stability, slope, texture, organic matter content, and parent material (Bryan 1977, Dyrness 1967).

(i) Since the resistance of surface soil to detachment and transport is closely related to aggregate stability to water, most indices of erodibility incorporate measures of this property (Bryan 1977, Dyrness 1967). In an extensive study of aggregate stability and erodibility of Albertan soils, Bryan (1977) concluded that the most useful index of erodibility was the percentage of water stable aggregate 0.5 m in size. Burning has had variable effects on aggregate stability. Intense burns are likely to destroy aggregates due to destruction of organic matter (Dyrness 1967, Dyrness and Youngberg 1957).

(ii) Many studies, particularly those reporting enhanced soil erosion following slashburning, emphasize the importance of slope. Little erosion is possible on flat terrain.

(iii) With respect to texture, silt-size particles are the most erodible because they are small and easily transported and they lack the cohesion of clay particles. Erodibility decreases as the percentage of either sand or clay-size particles increases. In the Douglas-fir region of Washington and Oregon, the following order of erodibility has been proposed (Western Forestry and Conservation Association 1957): unconsolidated silt consolidated silt silty clay loam, silty clay, some sandy clays, some clays clay loam, silty loam, some sandy clays, some clays loamy sand, sandy loam, sand, cohesive well compacted clays coarse sand fine gravel rock, cobble, gravel. However, erosion from fire-induced water repellent layers in soils is more serious in coarser textured soils (DeBano and Rice 1971, Dyrness 1976).

(iv) Organic matter is an important cementing agent in the formation of aggregates and is consequently closely related to soil erodibility (Dyrness 1967).

Parent material greatly influences soil properties and has been related to erodibility. Work in Washington and California has indicated that soils derived from acid igneous rock are particularly erodible (Dyrness 1967). Wallis and Willen (1963) ranked parent materials in California according to the erodibility of soils formed from them, as follows:

most erodible: granite, quartz diorite, granodiorite, Cenozoic non-marine sediments, schist.

intermediate: diorite, several meamorphic rocks.

least erodible: Cenozoic and pre-Cenozoic marine sediments, basalt, gabbro, peridotite, serpentinite, and andesite.

(c) Rate of revegetation

The rate of revegetation determines the rate at which the soil is protected against the impact of raindrops, and the rate at which the soil is bound in place by roots. This will depend on a variety of ecological factors. Smith and Wass (1976), working in the southern portion of B.C., considered that the rate of revegetation following clearcutting and slashburning was related to biogeoclimatic zone, being slowest in the Engelmann Spruce - Subalpine Fir (ESSF) Zone, faster in the Interior Western Hemlock (IWH) Zone, and faster again in the Interior Douglas-fir (IDF) Zone, although following clearcutting along the rate of revegetation increased in the order IWH ESSF IDF. Dyrness (1976) and Lafferty (1972) indicate that the rate of revegetation may depend on the type and intensity of the fire.

(d) Degree of removal of the forest floor

The depth of the burn determines the degree of removal of the forest floor. Many workers have emphasized the hydrological importance of the forest floor which acts like a protective sponge covering the mineral soil (eg. Plamondon 1972, and references therein). Forest floors usually have very high infiltration capacities and protect the surface of the mineral soil from the impact of raindrops. The severity of erosion following fire has been related to the degree of destruction of the forest floor (Dyrness 1967, Rice et al. 1972, Rothacher and Lopushinsky 1974, Youngberg 1953).

(e) Intensity of the burn

The extent to which a fire causes the changes in the soil physical properties discussed above, and hence the effect of the fire on the severity of soil erosion, has been related to the intensity of the fire (Dyrness 1967, Rice et al. 1972, Tarrant 1956). However, measures of the intensity of the fire have been fairly crude and subjective.

(d) Mass wasting

Mass wasting can be a serious problem in the mountainous region of the North American west coast, where steep slopes and heavy precipitation occur. Mass wasting is often particularly serious in parts of this region affected by timber harvesting operrations (Ballard and Willington 1975, Gresswell et al. 1979, O'Loughlin 1972, Rice and Krammes 1971, Swanston 1971, 1974a, 1974b, 1976, Swanston and Dyrness 1973, Swanston and Swanson 1976, Utzig and Herring 1974, Wu and Swanston 1980, Ziemer 1981).

Forests help to minimize mass wasting in two major ways. Firstly they reduce the amount of water reaching the soil and the amount of water stored in the soil, mainly through a combination of interception and evapotranspiration. However, during high rainfall events interception may be negligible and during winter evapotranspiration may be negligible (Swanston and Swanson 1976). Forests may also moderate the rate at which water enters the soil, which can be particularly important in the case of warm-rain-on-snow events. Forest cutting will increase the amount of water entering, and stored in, the soil, thus increasing the soil pore-water pressure, rendering a slope more susceptible to failure (Gresswell et al. 1979, O'Loughlin 1972, Swanston 1974a, 1974b, 1976, Swanston and Swanson 1976, Wu and Swanston 1980, Ziemer 1981).

Secondly, the roots of forest plants add strength to the soil. They may anchor the soil mass into fractures in bedrock and they may laterally tie a

slope together across zones of weakness or instability. Forest cutting will result in the decay of root systems rendering a slope more susceptible to failure (Burroughs and Thomas 1977, O'Loughlin 1972, 1974, Swanston 1974a, 1974b, 1976, Swanston and Swanson 1976, Wu and Swanston 1980, Ziemer 1981, Ziemer and Swanston 1977).

Slashburning, by causing more complete destruction of vegetation than tree cutting alone, is considered to accelerate mass soil movement (Swanston 1971, Swanston and Dyrness 1973).

3. Effects of slashburning on water quality

Slashburning may significantly affect water quality parameters. Firstly, as discussed above, slashburning can increase soil erosion. If this eroded soil enters a stream then slashburning will have caused increased stream sediment levels, as has been found by several workers (eg. Brown and Krygier 1971, Dyrness 1967, Fredriksen 1970, Rice et al. 1972).

Slashburning may exacerbate changes in stream temperature regimes caused by clearcutting. Slashburning has been reported to increase summer temperatures and daily temperature fluctuations in small streams (Feller 1981, Levo and Rothacher 1969).

Slashburning has also increased nutrient concentrations in streams (Feller and Kimmins 1982, Fredriksen 1971) (see also Figure 1). Rothacher and Lopushinsky (1974) considered that the quantity of chemicals reaching streams following slashburning is roughly proportional to the quantity of fuel burned.

All the changes in streams discussed above may effect fish and fish food organisms. Although there have been several studies on the effects of timber harvesting on fish populations, very few have separated out the effects of slashburning. Hall and Lantz (1969) reported that a slashburn in coastal

Oregon increased stream temperatures during the fire, from 13°C to at least 28°C causing the death of many juvenile coho salmon, cutthroat trout, and sculpins. If slashburning does cause increases in summer stream temperatures, increases in stream sediment levels, or decreases in plant and insect material falling into streams, then fish populations may be adversely affected (Brown 1974, 1980, Chapman 1962, Cordone and Kelley 1961, Hall and Lantz 1969, Lantz 1971, Narver 1972).

These impacts on fish and aquatic ecosystems are strongly related to the treatment given to riparian vegetation. If this streamside vegetation is left relatively undisturbed and can protect the stream from logging- or slashburning-induced changes to its environment, then slashburning an area adjacent to a stream may have no significant impact on streamwater quality or on fish populations in that stream (Brown 1974, 1980, Hall and Lantz 1969).

## GENERAL CONCLUSIONS

Many conclusions specific to individual studies concerning the effects of slashburning can be extracted from the literature discussed above, but due to the complexity of forest ecosystems and their interrelationships with timber harvesting and slashburning, few general conclusions can be drawn. It is clear, however, that different forest ecosystems will respond to slashburning in different ways, depending on the characteristics of the ecosystem, climatic conditions prior to, during, and after burning, and the intensity and depth of the burn. This response may be positive or negative from the forest manager's viewpoint. It is unfortunate that much of the slashburning literature, particularly that concerned with the impact of slashburning on tree species, does not recognize the fact that the impacts of slashburning are site- or ecosystem-specific. The ecosystems subjected to slashburning, and the slash fires themselves, have often been poorly characterized.

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# DOCUMENTATION OF PRESCRIBED FIRE BEHAVIOUR AND EFFECTS ON FOREST FUELS

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# DOCUMENTATION OF PRESCRIBED FIRE BEHAVIOUR AND EFFECTS ON FOREST FUELS

## A. Introduction

Prescribed burning has been defined by Muraro (1975) as "the knowledgeable application of fire to a specific land area to accomplish designated land management objectives". The main uses of prescribed burning in B.C. are for silvicultural, protection (hazard reduction and sanitation), wildlife habitat management and domestic grazing purposes. The focus of this paper will be on the documentation of prescribed fire used in silvicultural and protection applications.

There are several reasons why documenting prescribed fire behaviour and effects on forest fuels would provide useful information for both research and operational personnel. These are:

a) The recent change in emphasis of post-logging prescribed fire objectives from protection (mostly hazard abatement) to silvicultural under Section 88 of the B.C. Forest Act has required closer examination of specific silvicultural objectives of burning and whether or not they are being satisfactorily achieved. A desire to achieve more specific silvicultural objectives has lead to a need for burning prescriptions to specify a desired level of slash consumption, organic layer (LFH) reduction and mineral soil exposure. Documentation of prescribed fire effects on fuels will provide the detailed information necessary to determine if the burn objectives have been achieved. Visual estimates might also be improved if they are occasionally backed up with measured documentation of fuel effects.

b) Research projects which involve prescribed burning need quantitative documentation of fire behaviour and effects on fuels to produce the desired improvement in understanding and predictability of the ecological effects of fire. One of the major problems in interpreting past research

on prescribed fire ecological effects is the lack of documentation of the fires which have produced the effects.

c) Well documented prescribed fires can provide a data base to aid in prescription formulation. This information should also be useful in improving or adjusting the Prescribed Fire Predictor (Muraro 1975).

## B. Objective of Paper

This paper is not a handbook of detailed procedures for documenting prescribed burns. A manual or handbook for B.C. conditions is now in the planning stages by PFRC fire research staff. The purpose of this paper is to provide a brief overview of what and how to measure fire behavior and its impact on fuels. This paper is not directed towards research or operation staff in particular. A suggested operation level of measurements is outlined in the discussion section.

The paper is presented in a point format with the following aspects of prescribed fire documentation covered:

a) current measurement techniques in preburn slash and organic layer loading.

b) fire behaviour documentation techniques, including rate of spread and problems with spread determination when ignition pattern does not use strip-head firing. Fire weather and fuel moisture determination will also be discussed.

c) post-fire fuel consumption and mineral soil exposure.

d) calculation of frontal fire intensity.

## C. Pre-Burn Measurements

### 1. Fire Weather

a) Past and present weather documentation is necessary in the planning and selection of burning conditions requried to meet the prescription, in terms of expected fire behaviour and impact on fuels. Weather should be monitored for the entire fire season if accurate fuel moisture codes are to be calculated (Lawson 1981), but due to cost constraints this cannot always be done. Current developments in automatic electronic fire weather stations have made this monitoring more feasible in terms of extended periods of maintenance - free data storage, easy data retrieval in digital form, and more reasonable costs (Lawson 1981).

b) A compromise to full season weather monitoring would be a short-term weather station established on-site 2 to 3 weeks in advance of a prescribed burn which would provide temperature, relative humidity and precipitation data to adjust DMC and DC values from the most representative permanent station (Lawson 1981).

c) More rigorous adjustment techniques for adjusting off-site moisture codes to on-site conditions for start-up values and to adjust on-site codes to local variations in slope and aspect are still in development.

d) Turner and Lawson (1978) provide details on weather station location and fire weather recording.

### 2. Slash Loading

a) The most widely used system for estimating slash loading is the line intersect fuel sampling method developed by Van Wagner (1965,

1968) with further work by Brown (1971) and Brown and Roussopoulos (1974). A handbook was developed by Brown (1974) for inventorying downed woody material using this system in the U.S. McRae et al. (1979) have prepared a handbook which uses this system with some modifications to speed up sampling and with all units of measurement in the metric (SI) system. The main modification in the sampling scheme is the use of a sampling triangle rather than a grid of transects across the prescribed burn block. The sampling triangles are distributed over the prescribed burn block which is usually pre-stratified into sections having similar slash fuel characteristics (ie. arrangement, species composition, depth, etc.). This triangle sampling system was recently used to advantage in B.C. by Canadian Foestry Service staff as part of the monitoring of a site rehabilitation burn near Chilliwack, B.C. (Lawson 1982). In heavy slash loading situations such as this one, the triangular transect arrangement reduces sampling time.

b) Slash loading is determined by size class of fuels. This permits evaluation of fuel consumption by size class which is the approach used in the Prescribed Fire Predictor to evaluate fire impact on fuels. In terms of slash consumption, most burn objectives are expressed by size class (eg. the primary objective for hazard abatement might be to reduce slash fuels  7 cm by 80%).

c) Slash loading by size class is also needed if a foliage-to-branchwood ratio is used to estimate foliage loading.

3. Slash Depth

Slash depth has been measured in two ways; total depth which is the highest intercept depth at the sample point and average or bulk (Albini and Brown 1978) depth which is generally described as an estimate of the average slash fuel bed depth. It is more difficult to obtain consistant measurements of average depth among different

samplers but average depth is more useful for correlation with slash loading. Measurements along the fuel loading transects of both total slash depth and average depth are desirable. If slash loading cannot be measured on a particular burn, enough well distributed slash depth, measurements at the same locations pre and post-burn, coupled with previous slash loading information on other burns in those slash types, can give a rough approximation of slash consumption.

4. Organic Layer Depth and Loading

a) Organic layer depth is usually measured by the separate layers (ie. moss, litter (L), fermentation (F) and humus (H) layers) where recognizable. Organic layer depths are generally measured in conjunction with the line intersect transects established for slash fuel loading.

b) Depth-of-burn pins are placed along the line intersect transects prior to burning so that organic layer removal can be measured. Pre-burn organic layer depth measurements are made adjacent to these pins. Examples of two types of depth-of-burn pins are illustrated in Figure 1 from McRae et al. (1979).

c) Organic layer loading estimates are not usually required as part of prescribed burn objectives of treatment, since the desired fire impact on organic layer is normally expressed as a depth of burn or percent reduction of organic layer depth. However, organic layer loading estimates are required as part of total fuel consumption calculations and in calculations of fire intensity and total fire energy output. Organic layer loading can be estimated by two methods; the first uses the measured depths in a previously derived regression equation to estimate loading; the second requires destructive organic layer sampling. The destructive method is more time consuming in the field and requires drying oven facilities, a weighing balance and preferably a muffle

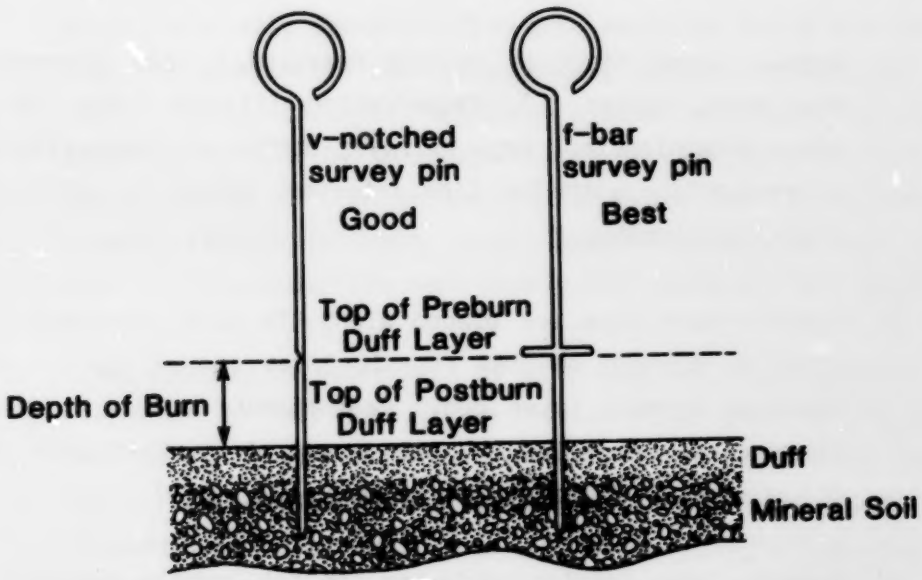


Figure 1. Two types of depth-of-burn pins (from McRae et al. (1979))

furnace to determine the amount of mineral soil incorporated in the organic matter. A regression line or equation for the specific site is then calculated from the sampled depth and loading data. The regression can then be used as in the first method to estimate organic layer depth taken and mean loadings calculated for the site.

5. Mineral Soil Exposure

An estimate of pre-burn mineral soil exposure is needed because logging activities and natural events (eg. snag blowdown) can expose significant amounts of mineral soil. Estimates are usually taken in conjunction with fuel sampling on the line intersect transects.

6. Shrubs, Grass and Herbaceous Loading

Shrubs, grass and herbaceous vegetation is not usually measured for loading when documenting prescribed burns because destructive sampling is too time consuming. Loading estimates based on sample measurements of shrub basal diameter or herbaceous percent cover by species can be derived from published regression equations. Burn objectives usually do not specify a desired proportion of vegetation consumption, although on productive sites, reducing vegetation competition is often a silvicultural objective. Reduction of shrub and herbaceous competition depends on many other more significant factors than consumption by the fire. Percent cover by species of shrub and herbaceous vegetation estimated on pre-burn plots would be useful for prediction and monitoring of post-burn vegetation recovery over time. A portion of vegetation consumption theoretically should be included in the frontal fire intensity calculation but is usually not included due to sampling time required. McRae et al. (1979) have not outlined sampling procedure in their handbook for understory vegetation, but any burns to be used for research purposes will normally require at least some measure of occurence, abundance, volume or loading of herbs and shrubs.

7. Photography

a) Slides (35 mm) could be taken of some of the line intersect transects for training purposes to illustrate various fuel loading conditions and to document pre-burn slash and vegetation conditions.

b) A standard size marker included in the photograph provides a reference scale. Plot recorded details in the photograph add to its usefulness as a permanent record.

D. Observations During the Fire

1. Observation Personnel

a) Personnel who are responsible for monitoring fire behavior should be independent of ignition and suppression crews to be able to devote full attention to the monitoring activities.

b) Observational personnel should be included in the briefing of ignition personnel prior to light up so they are aware of the proposed ignition pattern. Observationl points can then be selected for best advantage while ensuring crew safety. Clearly, the fire boss must have full knowledge and control over the movements and stationing positions of observers during pre-light up preparedness and during actual ignition.

c) Photography (35 mm camera) is helpful in documenting many aspects of flame front characteristics. An audio tape recorder or written notes detailing time and location references is essential for a useful photographic record.

d) Colour or Black and White vidoe tape is excellent for fire behavior documentation and is more flexible than movie film as an analytical tool and as a training aid.

2. Rate of Spread

a) An estimation of rate of spread is needed in the calculation of frontal fire intensity. Rate of spread can only be estimated when the ignition pattern includes headfires, backfires and flank fires. Rate of spread is impossible to document on prescribed burns with a centre or perimeter firing pattern or narrow strip headfires (McRae et al. 1979).

b) There are a number of methods available to document rate of spread which require a minimum amount of equipment; 1) a stopwatch and pacing is suited for an expected slow rate of spread. 2) a grid marking system set up before ignition is useful when a fast rate of spread is expected. 3) large prescribed burns (greater than 100 ha) should be observed from a vantage point (ie. a hill top, helicopter). Spread contours and times should be mapped, using landmarks for reference points. Distances between landmarks for reference points. Distances between landmarks used in spread rate documentation can be measured after the burn.

c) Rate of spread is variable over the prescribed burn block. Separate rate of spread estimates should be made for each fuel type or topographic unit or stratum that has been delineated during pre-burn fuel sampling if possible.

3. Spotting

a) If spotting occurs outside the burn perimeter take notes on time, distance from fire front and location on a map.

b) Notes should be made on the difficulty of control in the adjacent stand to compare with the Control Rank estimated by the Prescribed Fire Predictor.

4. Flame Front Characteristics

a) Estimation of flame length and depth should be made in conjunction with the rate of spread estimation. Figure 2 shows these parameters for a wind-driven fire on a slope. This figure is taken from a recent publication on measuring and interpreting fire behaviour for correlation with fire effects published by the U.S. Forest Service (Rothermel and Deeming 1980).

b) Flame length (the distance betwen the tip of the flame and the ground or surface of the remaining fuel midway in the zone of active flaming (Rothermel and Deeming 1980)) can be used in an equation developed by Byram (1959) to estimate frontal fire intensity;

$$I = 258\ (FL)^{2.17}$$

Where:

I is frontal fire intensity (kW/m)
FL is flame length (m)

Estimation of flame length is difficult for two reasons; 1) there is difficulty in identifying its dimension in an actual flaming front and 2) a scale (eg. metal posts with markers) is needed to help estimate flame length.

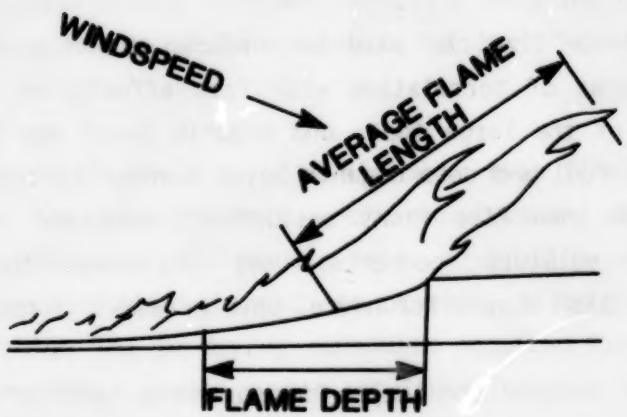


Figure 2 - Flame dimensions shown for a wind-driven fire on a slope (from Rothermel and Deeming 1980)

c) Flame depth (the distance at the base of the flame from the leading edge to the rear) is also difficult to estimate. It is used in the calculation of residence time (the length of time for the fire front to pass a point) along with the rate of spread in the following formula;

$$t_r = \frac{D}{R}$$

where:

$t_r$ is residence time (min)
D is the flame depth (m)
R is the rate of spread (m/min)

Residence time can also be measured directly at the fire front. In terms of correlating with fire effects on soils, the burnout time of the large fuels and organic layer may be more important. Large fuel and deep organic layer burnout times generally are much longer than fire front residence times, and depending on heavy fuel moisture contents, may continue through smouldering combustion stages for hours, days or weeks if not mopped up.

d) Flame length and depth measurements are of little use when attempted on large burns with great masses of flame (Rothermel and Deeming 1980).

5. Fire Weather

a) Fire weather was already discussed in the section on pre-burn measurements. In addition to standard fire weather readings at 1300 hours preceding the burn, observations of temperature, relative humidity and wind velocity should be taken immediately preceding and during the burn. Weather conditions can change as the burn proceeds especially when it occurs over a long time period. On-site weather measurements at time of ignition can be used to calculate a Fine Fuel Moisture Code corrected for ignition time.

b) Diurnal adjustment tables might be used to adjust 1300 hour Fine Fuel Moisture Code to time of ignition if a weather station is not on-site (Anon. 1973).

6. Fuel Moisture

a) One way to bypass the need for many weeks of on-site weather measurements is direct measurement of fuel moisture of various types and sizes of fuel but direct fuel moisture determination presents many difficulties in standardizing measurement and tends to substitute one set of problems for another (Lawson 1982).

b) A forced-air drying oven and sensitive weighing balance is needed for determination of fuel moisture but procedures are not outlined here.

c) Experiences in the U.S. with microwave oven fine fuel drying have sparked interest in this technique because of reduced drying time. Inconsistent results are a problem which limit the usefulness of this approach at present, although improvements in oven design and in drying schedules required for different fuels may make this a viable system, at least for fine dead fuels.

E. Post-Burn Measurements

1. Slash Consumption

a) Post-burn slash measurements are made using the line intersect method along the same transects located during pre-burn measurements. Re-measurement of the line intersect transects provides the information to determine slash consumption.

b) Re-measurement of slash 7 cm is the same as pre-burn procedures. Measurement of logs 7 cm requires the re-location of nails which were driven in before the burn. Foliage is not usually re-measured because most prescribed burns will consume the foliage portion of the fuel bed.

2. Organic Layer Consumption

a) Depth-of-burn pins are relocated on the line intersect transects and depth of burn is measured (measured to unburned organic material).

b) Published regression equations or those derived from destructive organic layer samples are used as in pre-burn loading determination to estimate total organic layer consumption.

3. Shrubs, Grass and Herbaceous Consumption

As mentioned previously, shrubs, grass and herbaceous vegetation is not usually measured. Most grass and herbaceous vegetation would normally be consumed in a prescribed burn. Shrubs might only be partially consumed and would require re-measurement. Procedures would involve some form of destructive sampling.

4. Mineral Soil Exposure

Post-burn mineral soil exposure is estimated in the same locations on the sampling triangles as the pre-burn estimates. Transect distances can be increased to improve mineral soil exposure estimates by estimating exposure along transects from perimeter tie points to sampling triangles and between sampling triangles.

## F. Calculation of Frontal Fire Intensity

a) Frontal fire intensity calculation procedures have varied in the literature although its definition is standardized. Frontal fire intensity (Van Wagner 1978) is the area of energy output per unit length of the fire front, expressed in S.I. units as kilowatts (combines energy and time) per meter (kW/m). Lawson (1981) described the various methods used to calculate fire intensity. Alexander (1981) has described the limitations of using intensity to correlate with fire effects. Total fuel consumption seems to be the best correlation parameter with nutrient effects and depth of burn with shrub, grass and herbaceous response after fire and seedbed conditions (Alexander 1981).

b) Lawson (1981) summed up the frontal fire intensity calculation differences in the literature and offered a possible solution for the present, which is to sample pre- and post-burn slash fuels by size class, as suggested by McRae et al. (1979), so that fuel consumption data, in total or in part, are available for fire intensity calculation.

c) The documentation manual in preparation by C.F.S. will probably recommend inclusion of total fuel consumption in the intensity calculation as done in McRae et al. (1979).

## G. Discussion

### 1. Operational Level Documentation

a) In Ontario, the Ministry of Natural Resources requires the measurement of pre- and post fuel loading with fire behavior documentation on all operation prescribed burns conducted by the

Ministry (Doug McRae, C.F.S., personal communication). In B.C., no documentation of fire behavior or fuel effects are required, except for estimates of slash and organic layer consumption as specified by the B.C.M.F. prescribed burn analysis form (FS 117A).

b) After reviewing a number of B.C.M.F. regional guidelines on prescribed burning as a silvicultural treatment, it appears that organic layer reduction is listed as a critical factor in maintaining or improving productivity on may sites. Organic layer consumption documentation on these sites might be considered a minimum along with adequate on-site fire weather information.

c) Keeping in mind that frontal fire intensity is not directly related to organic layer consumption, rate of spread, flame and length and slash fuel consumption measurements might be considered optional for operational burns but could provide useful information for comparison of prescribed burn effects on different burns.

d) Measurements which would be more suited for research experiments would be fuel moisture, shrub, grass and herbaceous loading, slash depth and flame front characteristics.

2. Current Needs for Documentation

a) Qualitative estimates of the impact of prescribed burns (eg. B.C.M.F. form 117A) may not be adequate in determining if the prescribed burn objectives have been achieved.

b) Sensitive sites in terms of prescribed burning may need quantitative documentation of slash and organic layer consumption to determine the impact of burning on productivity.

c) Recommendations now provided on acceptable organic layer and slash reduction in current guidelines should be tested to determine if they are feasible in terms of what can be practically accomplished with prescribed burning. An example is the current Prince Rupert Forest Region guidelines on site treatment by ecosystem, which state for many sites, that only the litter layer should be removed. Is this possible and what burning prescription can be written and obtained which might achieve this?

d) Research experiments or trials involving prescribed burning require better documentation of the fire that has caused the vegetation and soil effects being studied.

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# THE BURNING QUESTION:
# FOREST SOILS IN PERSPECTIVE

B.M. Geisler[1]

Forest Soil is only one, often an important one of many factors to consider in the prescribed burning decision making process. The flow chart shown in Figure 1 is an example of such a process applicable immediately after harvesting. Its purpose in the context of this conference is to put prescribed fire - forest soil impact considerations into perspective within the total prescribed fire decision making process. The body of the flow chart is a series of broad questions that can be combined into four modules; Initial concerns (1), Reforestation (2), Alternatives (3), and Opportunity of risk from prescribed burning (4). To progress through each module several more detailed questions need to be addressed and answered. Many of these are listed below.

1. Initial concerns.
   - Are there acceptable species on site, with adequate quality, distribution and survival chance?
   - Does the stand, slash, opening design or location pose an obvious and critical protection hazard?
   - Is there an obvious and critical site loss hazard associated with burning?

2. Reforestation.
   - How will the opening be restocked - naturally, artifically or a combination of the two?

   - Natural regen.
     - Are there sufficient viable seeds/cones?

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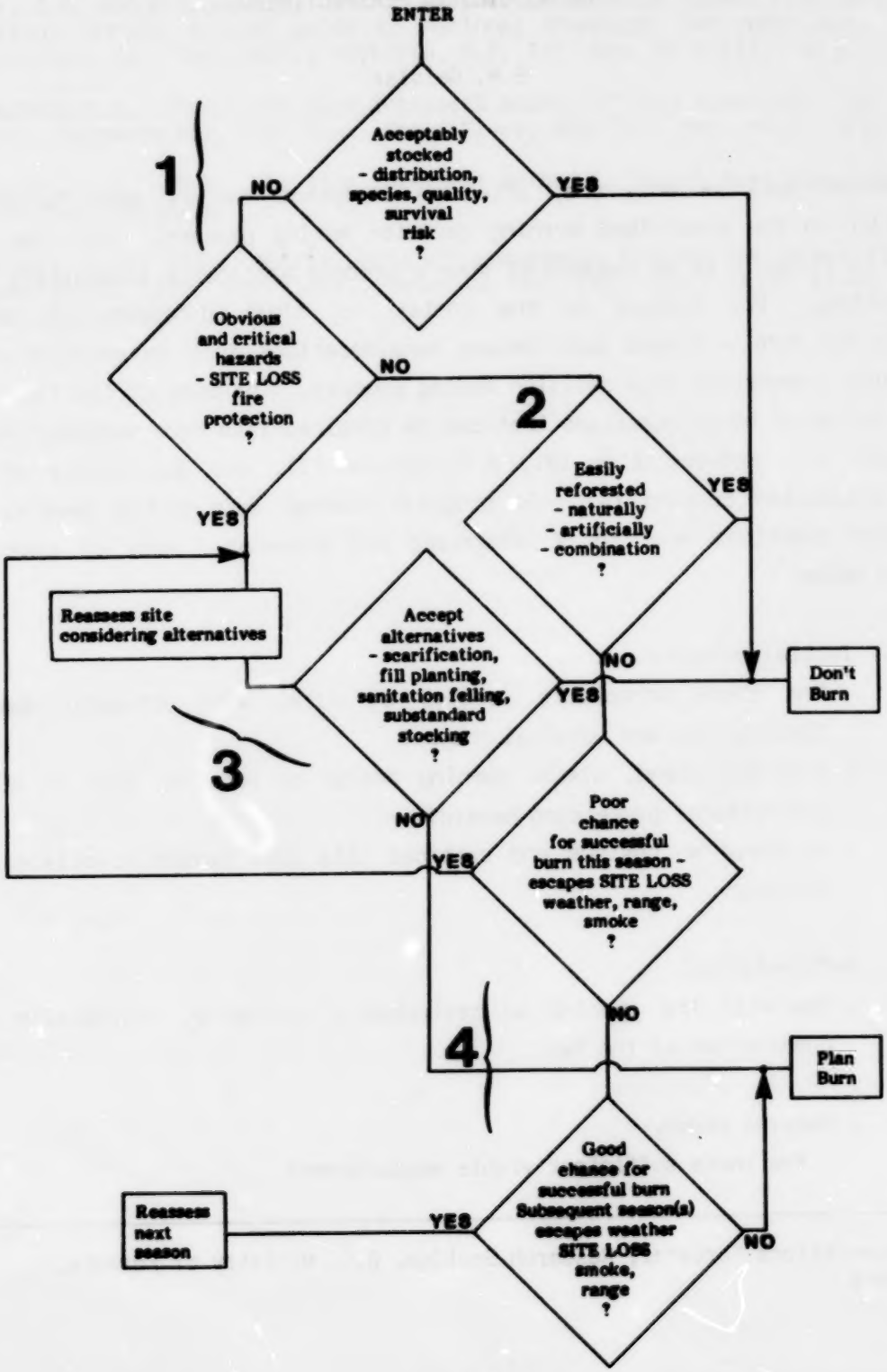
Figure 1. A post-logging decision making flow chart for prescribed burning.



- Are prevailing winds important?
- Is the size and shape of the opening appropriate?
- Is the number and distribution of potential seedbeds sufficient?

- Artificial regen.
  - Are there enough plantable spots?
  - Do planting crews have the appropriate experience?
  - Has crew moral and safety been considered?
  - Is the expected productivity acceptable?
  - What is the survival chance?

3. Alternatives.
   - Is there a less expensive or more effective way of dealing with the situation? (eg. scarification, chemicals, sanitation felling, chipping.)
   - Is it worthwhile to accept substandard advanced regen?
   - What are the long term implications and how should they modify present plans?

4. Opportunity for and risk from prescribed burning.
   - What are the climatic trends? What is the expected weather? (eg. drying trends, prevailing winds, soil moisture.)
   - Are the site conditions appropriate for a safe burn? (eg. topog., soil properties, vegetation and slash characteristics, opening shape and design.)
   - Have other resources been taken in account? (eg. range, wildlife, recreation, roads, powerlines.)
   - Will it be advantageous to wait until next year?

This list is not meant to be all inclusive but sufficient in detail and number to show how forest soils along wtih many other factors influence the decision making process.

In this flow chart forest soils directly influence the process in only two places; first in the 'Initial concern' module where obvious and critical site loss hazards may preclude burning; second in the 'Opportunity for and risk from prescribed burning' module where assumed non-critical site loss hazards may modify burning plans to maintain or enhance site productivity.

Forest soils are indirectly involved throughout the entire flow chart. For example, soil properties need to be addressed when considering if scarification or chemicals is a possible alternative. However these are second order influences and even though they are necessary and important, they are not pertinent to the impacts of prescribed fire and forest productivity (soils). The indirect involvements are outside the scope of this conference.

The purpose of this conference is specifically to address the direct influence of forest soils on the prescribed burning decision. Its objectives are first to establish the relevant state of knowledge and second to clarify research needs. In terms of the flow chart these objectives can be restated to read; first provide available answers to those questions addressing potential site loss or enhancement from prescribed burning and second, look for answers not yet available.

The example used here, the flow chart of figure 1, puts the topic of forest soils in perspective within the prescribed burning decision making process. Other examples or models could do the same.